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Functional Comparison of Created and Natural Wetlands in the Atchafalaya Delta, Louisiana

by Stephen P. Faulkner and Matthew E. Poach



September 1996 – Final Report

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	Task		Task
CP	Critical Processes	RE	Restoration & Establishment
DE	Delineation & Evaluation	SM	Stewardship & Management

Wetlands Research Program

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by Stephen P. Faulkner, Matthew E. Poach

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Final report

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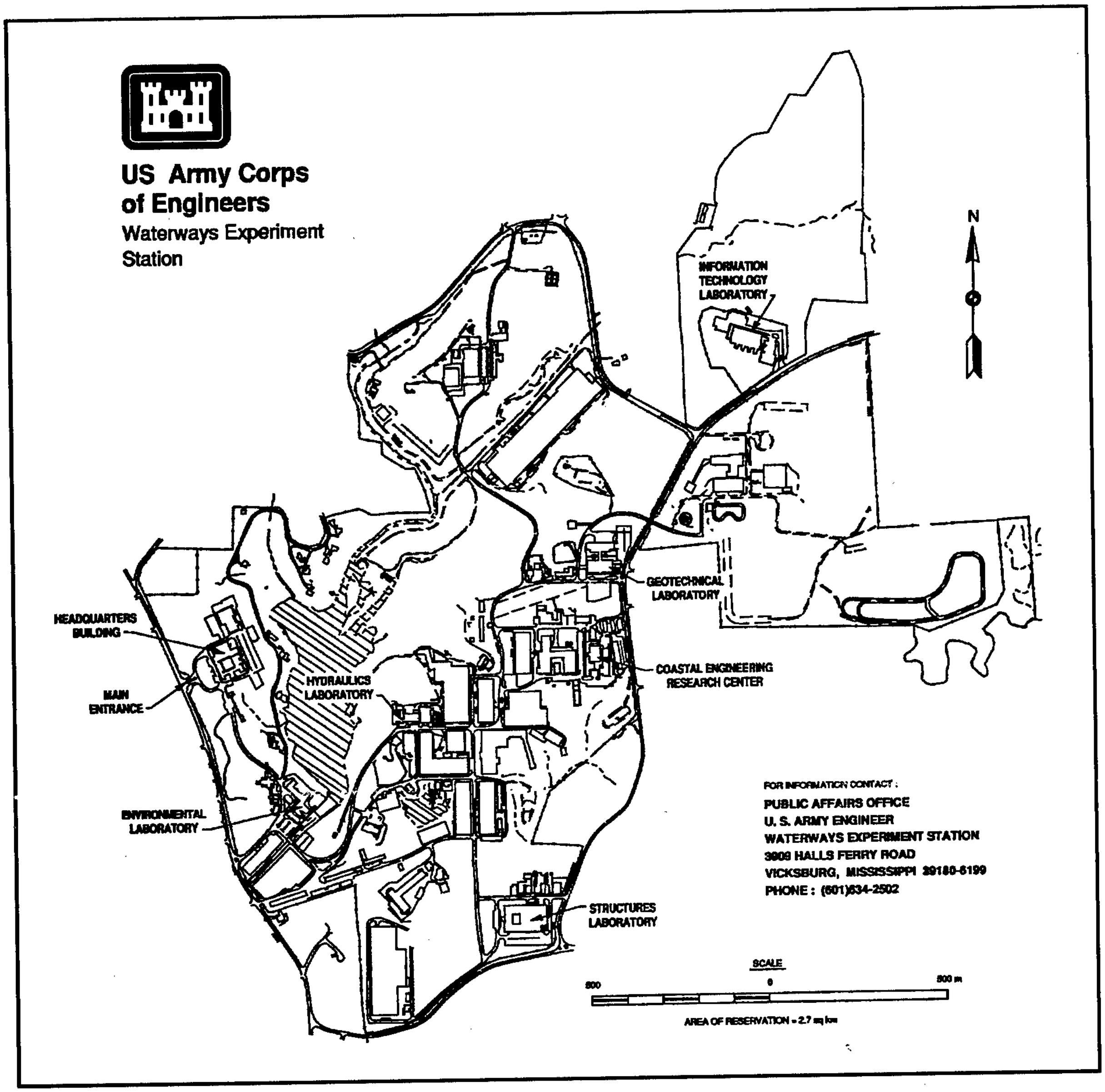

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Wetland Restoration

Functional Comparison of Created and Natural Wetlands in the Atchafalaya Delta, Louisiana (TR WRP-RE-16)

ISSUE:

The ability of created wetlands to function as natural systems has been questioned because most wetlands studied have been new created wetlands instead of old natural wetlands. Quantitative data were needed to verify functional equivalency in wetlands of similar ages.

RESEARCH:

Functional assessment of created wetlands in comparison with natural wetlands of the same ages was undertaken in the Atchafalaya Basin, Louisiana. Objectives were to characterize the structural components of created and natural wetlands of similar age classes, compare and contrast selected wetland functions, and quantify any structural and functional changes that may occur as a function of time.

SUMMARY:

One natural and one created wetland was selected for each of three age classes. An additional natural "old" wetland was added to ensure a valid comparison. Soils were evaluated for bulk density, pH, moisture content, particle size, carbon, phosphorus content, and nitrogen content. Old wetlands were different from new wetlands in dominant species, and created wetlands of all ages had a higher diversity of species. Total above ground biomass was lower on created wetlands, but may have been due to nutria herbivory. New created marshes had obvious differences attributable to the dredging process necessary to create the wetland.

Results indicated that it takes from 5 to 10 years for a created wetland in the Atchafalaya Delta to develop similar soil and vegetation characteristics to a natural reference wetland of the same age.

AVAILABILITY OF REPORT:

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Preface

The work described in this report was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Restoration and Establishment of Wetlands Task Area of the Wetlands Research Program (WRP). The work was performed under Work Unit 32758, "Improved Wetlands Design Criteria," for which Dr. Lawson M. Smith was the Technical Manager. Ms. Denise White (CECW-ON) was the WRP Technical Monitor for the work.

Mr. Dave Mathis (CERD-C) was the WRP Coordinator at the Directorate of Research and Development, HQUSACE; Dr. William L. Klesch (CECW-PO) served as the WRP Technical Monitor's Representative; Dr. Russell F. Theriot, U.S. Army Engineer Waterways Experiment Station (WES), was the Wetlands Program Manager. Dr. Mary C. Landin, WES, was the Task Area Manager.

This report was prepared by Dr. Stephen P. Faulkner and Mr. Matthew E. Poach, Wetland Biogeochemistry Institute, Louisiana State University, Baton Rouge, LA, under the general supervision of Dr. Landin, Technical Task Manager; Mr. Ellis J. Clairain, Jr., Acting Chief, Wetlands Branch; Dr. Conrad J. Kirby, Chief, Ecological Research Division, Environmental Laboratory (EL), WES; Dr. Edwin A. Theriot, Assistant Director, EL; and Dr. John W. Keeley, Director, EL. The report was reviewed by Drs. Landin and Mary M. Davis, EL.

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1 Introduction

Nationwide, over 50 percent of the historical (pre-1780) wetlands have been lost with individual state losses as high as 90 percent (Dahl 1990). These losses, combined with an increased understanding of wetland functions, have heightened awareness of the important roles of wetlands in the watershed. This importance is manifested in the Federal and State regulations that protect wetlands. While the first level of protection is impact avoidance, wetland loss or degradation is often unavoidable in today's society.

Wetland loss or degradation is accounted for in regulatory programs by requiring compensatory mitigation through wetlands restoration (rehabilitating a degraded existing wetland or a hydric soil area that was previously wetland) or creation (converting a nonwetland area to wetland) (Kruczynski 1989). This process has expanded to the point where mitigation banking (creating large wetland reserves prior to actual developmental activity) is becoming more common (Krohe 1989; Levin and Broadway 1990).

In addition to regulatory mitigation programs, numerous Federal agencies have developed wetland restoration/creation programs (Whitaker and Terrell 1992). The U.S. Army Corps of Engineers has been involved in wetland creation/restoration since the early 1970's primarily through their research program on dredged materials (Landin, Webb, and Knutson 1989). The U.S. Department of Agriculture (USDA) has initiated a Wetlands Reserve Program (WRP). The program goal is to improve water quality, wildlife habitat, and soil conservation by restoring 405,000 ha of cropland back to wetlands by 1995 (USDA 1992). While funding through 1995 is not certain, the $46.4 million allocated for the 1992 pilot program will restore 20,250 ha in nine states: California, Iowa, Louisiana, Minnesota, Mississippi, Missouri, New York, North Carolina, and Wisconsin. Of the 188,730 ha offered for inclusion in the pilot program, 94,770 ha were in Louisiana and Mississippi alone (USDA 1992). Under a similar Crop Reserve Program (CRP), over 5,000 ha of wetlands have been restored (Whitaker and Terrell 1992).

The combination of compensatory mitigation and current Federal programs indicates a tremendous increase in the acreage of created/restored wetlands. The basic premise of wetland creation and restoration projects is that these areas will provide wetland functions associated with natural wetlands in addition to the structural components (e.g., vegetation) of the wetland itself.

Those functions associated with restoring and maintaining the chemical, physical, and biological integrity of the Nation's waters are generally emphasized. These functions include water quality improvement (nutrient transformation, contaminant processing, sediment removal), hydrologic alteration (flood storage, recharge), and wildlife habitat (fish, waterfowl). While the functional attributes of natural wetlands are well documented (Mitsch and Gosselink 1986; Nixon and Lee 1986; Faulkner and Richardson 1989), creating or restoring those functions has been more problematic.

One problem is the tremendous diversity of natural wetlands, which results in a concomitant functional diversity. Very few individual wetlands will possess all of the natural functions attributed to wetlands in general. Specific functions, as well as their relative importance, will be determined primarily by wetland type and location within the watershed. This creates problems in wetland creation/restoration when specific goals are poorly defined and success criteria are tied to natural reference wetlands that are not directly comparable to the project. Even when the project objectives are well defined, successful creation/restoration has been difficult to achieve or assess. In many cases, because little or no follow-up monitoring occurs, there are no data with which to evaluate success or failure. A recent review of mitigation projects in Florida found only 12 percent of the freshwater projects and 45 percent of the tidal projects were functional wetlands or likely to become functional (Florida Department of Environmental Regulation 1991).

There are, of course, many instances of creation/restoration projects that satisfy the project goals or permit requirements (Broome 1989; Landin, Newling, and Clairain 1987). However, success may be determined solely by structural characteristics (vegetation survival, composition, density) or merely existence for the period of time designated by the permit (Shishler 1989; Stanley 1989). There are few studies that document ecosystem functions in a scientific manner. Craft, Seneca, and Broome (1991) determined that soil nutrients, physical properties, and chemical characteristics of a 5-year-old created marsh in North Carolina were different from those of a nearby natural marsh. Another created marsh in North Carolina supported faunal communities and food chains different from two adjacent natural marshes due to lower soil organic matter (Moy and Levin 1991). A 4-year-old created marsh in San Diego also had lower organic carbon, aboveground biomass, and nitrogen pools than an adjacent natural marsh (Langis, Zalejko, and Zedler 1991). The major weakness of these and other studies is the comparison of very young created wetlands to very old natural ecosystems. It is not logical to assume they would be similar, and some do not recommend using natural reference wetlands because of this very problem (Clewell and Lea 1989). Again, the lack of quality data constrains the ability to scientifically support or refute specific success criteria from a functional perspective. The next stage in the understanding of created wetlands must focus on the creation and maintenance of processes and functions that characterize wetlands.

The overall objectives of this study were to (a) characterize the structural components (soils and vegetation) of created wetlands and natural wetlands of

similar age classes, (b) compare and contrast selected wetland functions, and (c) quantify any structural and functional changes that may occur as a function of time.

2 Methods and Procedures

Study Location

The Atchafalaya Delta was selected as the location for the study sites because it is uniquely suited for this study. The gradient and flow efficiency of the Mississippi River have decreased to the point that a new channel to the Gulf of Mexico is favored. The Atchafalaya River is a natural distributary of the Mississippi River (Figure 1) that has captured increasing amounts of Mississippi River discharges and sediments over the years (Fisk 1952). This natural process was halted with the construction of a control structure in 1963 that maintains the Atchafalaya River flow at 30 percent of the combined Mississippi and Red River flow (Roberts and van Heerden 1992).

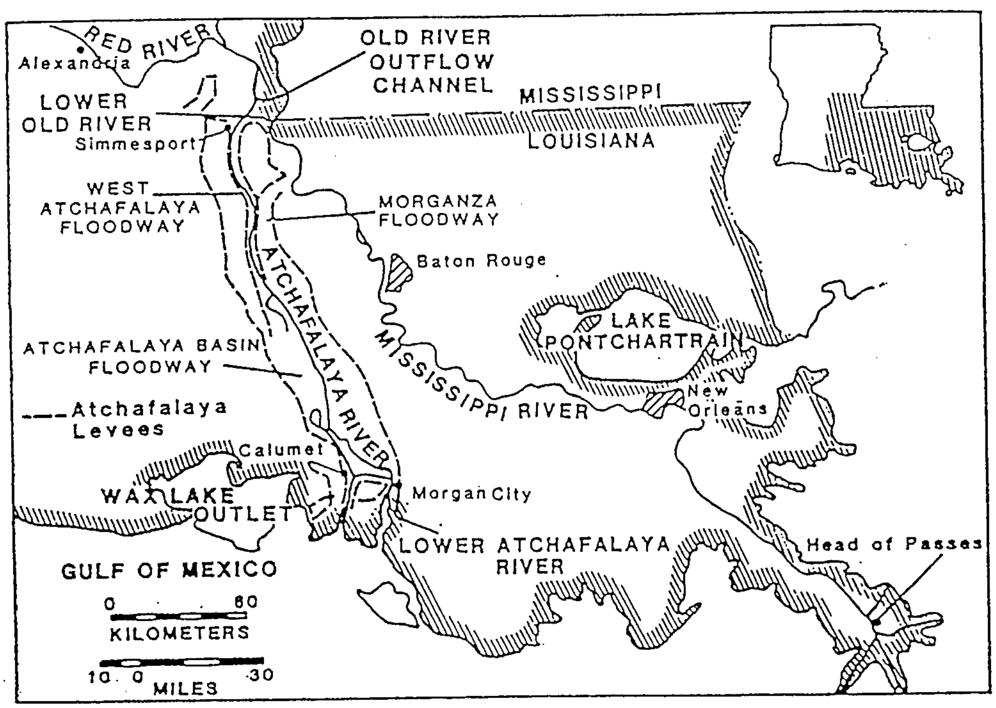

Figure 1. Location of the Mississippi and Atchafalaya Rivers in southern Louisiana. The Atchafalaya floodway levees are identified

As the sediment carried by the Atchafalaya River filled the Atchafalaya Basin to near capacity by the 1950's, additional sediment was carried downstream to the mouth of the river initiating subaqueous delta growth (Roberts, Adams, and Cunningham 1980). This new delta became subaerial in 1973 and has continued to expand (Figure 2). This provides a set of natural wetland islands ranging in age from 0 to 22 years.

In addition to these naturally created wetlands, wetlands have been created through U.S. Army Corps of Engineers dredging operations. The west channel of the Atchafalaya River is used for navigation by commercial vessels and must be dredged periodically to maintain the required depth. The dredged sediment material has been used to create wetlands since 1975. Therefore, within the same hydrologic regime exist both natural and artificially created wetlands of similar ages.

Aerial photography, satellite imagery, and records from the U.S. Army Corps of Engineers dredging program were used to locate and age both natural and created wetlands. From these data, one natural and one created wetland site were selected in each of three age classes: young (1 to 3 years), intermediate (5 to 10 years), and old (15 to 20 years). An additional natural wetland in the old age class was added when it was determined that the other natural site may have been impacted by dredged material.

The wetland formation processes resulted in an elevational gradient across the islands with a distinct plant community associated with specific elevations. Black willow (*Salix nigra*) was found on the higher elevation natural levees with a mixed freshwater marsh community at the next lower elevation (Figure 3). The lowest elevation areas were unvegetated mud flats.

Each island was stratified according to these elevational gradients, and three plots were established in each stratum. Relative elevations were determined with a laser level. Elevational differences among plots within a stratum were less than 5 cm.

Sediment Sampling

Two sediment cores (2.25 cm $\times$ 10 cm) were collected from each sample plot with a tube corer in October 1993, January 1994, May 1994, and July 1994. One core was placed in a 50-mL polypropylene centrifuge tube for bulk density, moisture content, and particle size (Patrick 1958) determinations. The second core was placed in a polyethylene bag for nitrogen (N) and phosphorus (P) determinations. The cores were transported on ice to the Wetland Biogeochemistry Institute laboratory, Louisiana State University, Baton Rouge, LA. All chemical analyses were conducted on wet soil (except where noted) and results reported on a oven-dry weight basis using the measured moisture content.

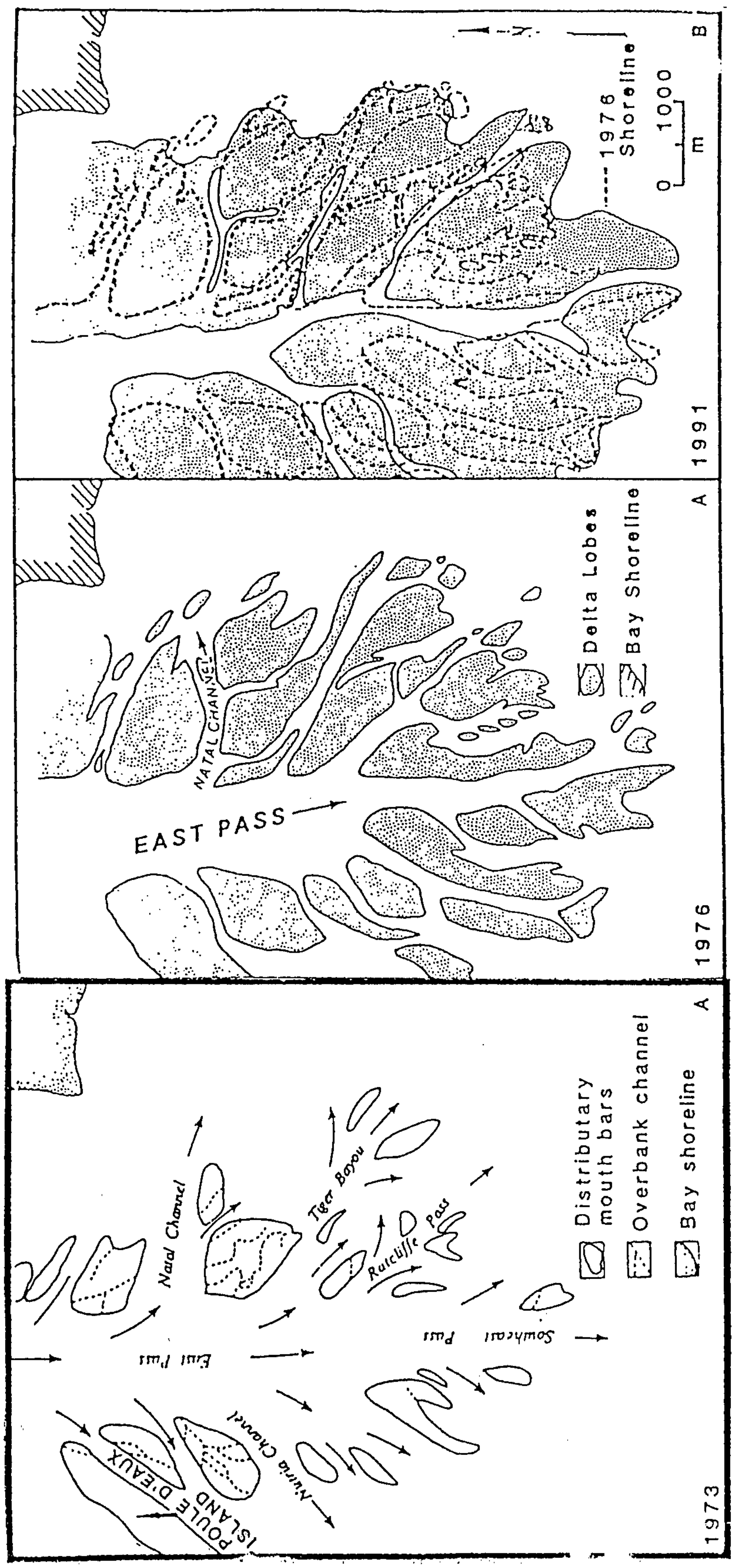

Figure 2. Progressive formation of the Atchafalaya Delta from 1973 through 1991

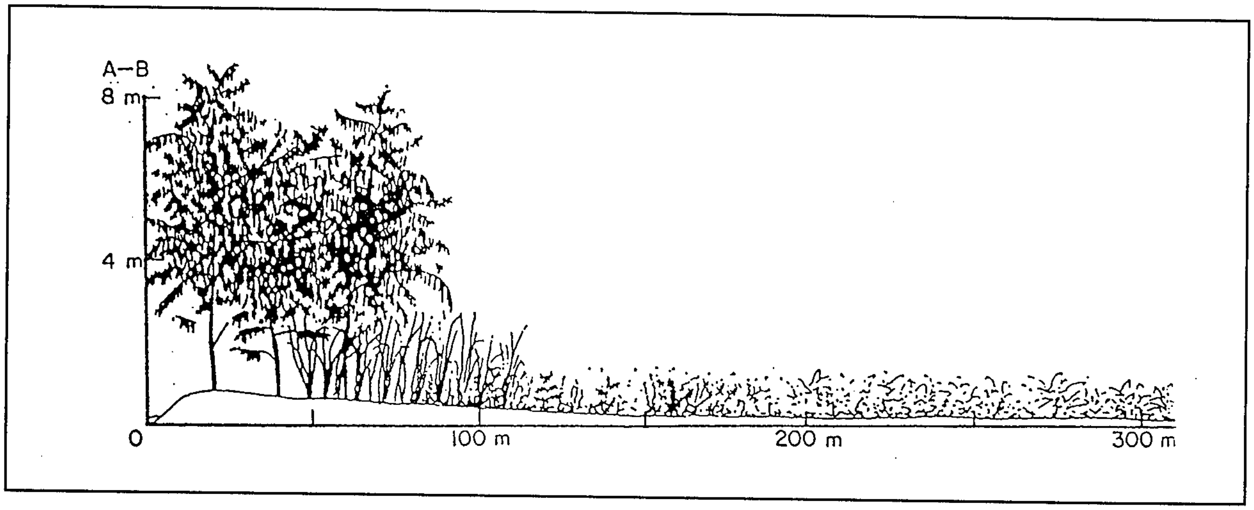

Figure 3. Generalized diagram of the elevational gradient across the natural wetlands in the Atchafalaya Delta, Louisiana

Phosphorus

Sediment cores were homogenized in the polyethylene bag at the Wetland Biogeochemistry Institute laboratory, and three subsamples were taken for analysis. Fractionation of soil P into iron- and aluminum-bound, reductant-soluble, and calcium-bound P was performed on a 1-g subsample using a modified Olsen and Sommers (1982) procedure (Figure 4). Modification of the procedure consisted of reducing the volume of extractants by half because of the use of field moist subsamples. Also, to remove the dithionite interference from the citrate-bicarbonate-dithionite (CBD) extract, extracts from the November, December, and January samples were acid digested according to the sulfuric-nitric acid method (Plumb 1981) before colorimetric analysis. Because acid digesting created some problems with analysis of P, dithionite interference in the May and July CBD extracts was removed by adding 5N H_2SO_4 to an aliquot of a sample, and precipitated dithionite was removed by centrifugation and filtration before colorimetric analysis. Total P was determined by acid digest of the second 1-g subsample (American Public Health Association (APHA) 1985). The final subsample was dried at 105 °C to constant weight to determine the oven-dry to wet weight ratio.

P in the citrate-bicarbonate, acid-digested CBD, and acidified CBD extracts was determined according to the method outlined by Weaver (1974). Total P and P in the remaining fractionation extracts were determined according to the method outlined by Murphy and Riley (1962) after neutralization of the extracts. Organic P was determined by subtracting the sum of the inorganic P fractions from the total P. The NaOH/NaCl and citrate-bicarbonate extracts were combined and operationally defined as iron- and aluminum-bound P. The CBD/NaCl extraction was defined as reductant-soluble P. Calcium-bound P was extracted by the HCl solution.

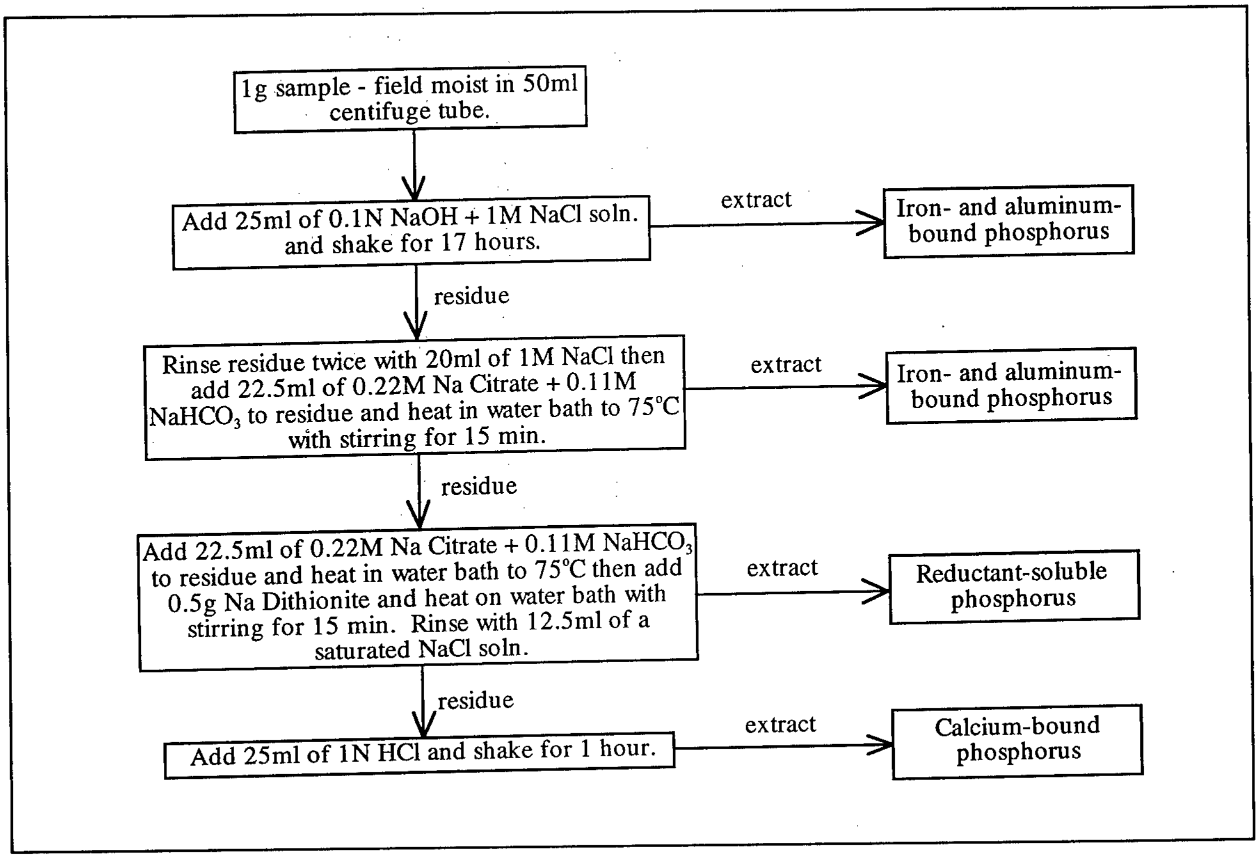

Figure 4. Soil phosphorus fractionation procedure (Olsen and Sommers 1982)

Anion exchange resin bags were used as another measure of soil P availability. Eight grams of DOWEX anion exchange resin were sealed in nylon mesh bags. The resin was converted to the bicarbonate form by two successive rinses in 0.5 M $NaHCO_3$ (Sibbeson 1978). One bag was incubated at each replicate sample plot within an elevational stratum for approximately 30 days in October 1993, January 1994, May 1994, and July 1994. A 10-cm-depth core was removed, the bags were placed at the bottom of the hole, and the core was replaced. After the bags were retrieved, they were washed free of sediment with DI water, and the phosphate accumulated on the resin was extracted by shaking the bags in 0.5 M HCl for 1 hour on a reciprocating shaker (Lajtha 1988). The supernatant was filtered through a Whatman No. 42 filter paper and the filtrate was analyzed for phosphate colorimetrically using the Murphy and Riley (1962) procedure.

Nitrogen

Sediment cores were homogenized in the polyethylene bag at the Wetland Biogeochemistry Institute laboratory. Soil nitrate and ammonium concentrations were determined by shaking 10 g of wet soil with 50 mL of 2 M KCl for 1 hour (Keeney and Nelson 1982). Samples were filtered through

Whatman No. 42 filter paper, and the filtrate was analyzed for nitrate and ammonium on a Wescan Model 3-60 Ammonium Analyzer (Alltech Corporation) equipped with a zinc reduction column. N-mineralization was measured using the buried bag technique (Eno 1960). When a sediment core was collected for nitrate and ammonium analysis, a second core was extracted, sealed in a polyethylene bag, and incubated in situ for approximately 30 days. The incubated core was retrieved and analyzed for nitrate and ammonium as previously described. Net mineralization was calculated as the difference in concentration between the initial and incubated cores.

Denitrification enzyme activity (DEA) (Phase I assay, Smith and Tiedje 1979) was determined by measuring nitrous oxide (N_2O) production from 25 g of wet soil amended with 25 mL of media containing dextrose (40 mg kg^{-1} soil), NO_3^--N (200 mg kg^{-1} soil), and chloramphenicol (10 mg kg^{-1} soil) (Groffman 1985). Samples were made anaerobic by purging with argon or nitrogen gas and incubated with 10 percent acetylene on a reciprocating shaker for 2 hours at room temperature (22 to 25 °C). Gas samples were removed with a gas-tight syringe and stored in evacuated glass tubes. Nitrous oxide was analyzed on a Tremetrics 9001 gas chromatograph equipped with a 63Ni electron capture detector and a Porapak Q column. Nitrous oxide dissolved in soil water was accounted for with the Bunsen adsorption coefficient (Tiedje 1982).

Total N and carbon were determined on a separate oven-dried subsample with a Fisons CHN analyzer (model EA 1108).

3 Results and Discussion

Most of the islands had an elevational gradient associated with different vegetation communities (Figure 3); however, not all sites had this feature. Both created and natural old age class (CO and NO) sites had high, middle, and low elevations as did the created young (CY) site (Table 1). Because natural formation processes involving sediment deposition would not be expected at a variety of elevations, the natural young and intermediate age classes (NY and NI) had only one elevation as did the created site of intermediate age (CI). As a result, data for all sites will be reported; however, comparisons among different sites will generally be restricted to the midelevation stratum since it is present in all age classes for both created and natural wetlands.

Table 1
General Characteristics of Created and Natural Wetland Study Sites in the Atchafalaya Delta

Site	Type	Age	Relative Elevation
Gary	Natural	Old (15-20 years)	High (0 cm)
			Middle (+2.4 cm)
			Low (-4 cm)
Log	Natural	Old	High (0 cm)
			Middle (-1.2 cm)
			Low (-25.3 cm)
Rodney	Natural	Intermediate (5-10 years)	Middle
		Young (1-3 years)	Middle
Montz	Created	Old	High (0 cm)
			Middle (-6.4 cm)
			Low (-28 cm)
Spoil	Created	Intermediate	Middle
Young	Created	Young	High (0 cm)
			Middle (-7.6 cm)
			Low (-22.9 cm)

General Characteristics

Differences in relative elevations were generally consistent across sites with the exception of Gary's Island where the midelevation stratum was actually 2.4 cm higher than the high-elevation stratum (Table 1). Efforts are continuing to tie these relative elevations into a known datum; however, this is a difficult task in the Atchafalaya Delta.[1]

As expected, there were no seasonal differences in total N, total carbon, bulk density, or pH; therefore, these results were averaged (Table 2). Total soil N at the midelevations was similar for all age classes with the exception of the CI wetland, which had a much higher accumulation of soil N (Figure 5). Among the old wetlands, the highest levels of soil N were measured at the high-elevation stratum (Figure 6). No differences between natural and created wetlands were noted in the old age class; however, no similar trend of increasing soil N with increasing elevation was observed for the CY wetland (Table 2). These trends paralleled those for total soil carbon (Figures 7 and 8), suggesting that accumulation of organic N was largely responsible for the observed differences.

Lindau and Hossner (1981) reported total Kjeldahl nitrogen (TKN) and organic matter concentrations were 2 to 4 times higher in natural marshes than in an experimental created marsh (less than 3 years old). However, they found higher concentrations of TKN and organic matter at lower elevations. Craft, Broome, and Seneca (1988) concluded that it would take longer than 30 years for nutrient pools in transplanted marshes to approximate those of natural marshes.

Bulk density was highest in the young age class and lowest in the old age class (Figure 9). The high organic matter content of the CI wetland was consistent with the low bulk density of those soils. A similar trend was noted for the high-elevation stratum of the old age class wetlands (Table 2). Soil pH was uniformly circumneutral with the highest values found at the CY wetland (Table 2).

Phosphorus

Mean P fractions, total P, and organic P concentrations per elevation at each site are presented in Tables 3 through 7. Because no seasonal trends were apparent, the data from all sampling dates were combined to give overall means for all P forms with the data from the NO wetlands being combined (Figures 10 and 11). Appendix A presents the seasonal data again with the data from the NO wetlands being combined. At the midelevation, the CO and CI soils had P concentrations similar to or greater than their comparably aged

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[1] R. Cunningham, U.S. Army Corps of Engineers, personal communication.

Table 2
Mean ($\pm$ se) Physical and Chemical Characteristics of Created and Natural Wetland Study Sites in the Atchafalaya Delta

Site	Type	Elevation	Percent		Bulk Density, g/cm^3	pH, s.u.
			Total N	Total C		
Gary	NO	High	0.20(0.04)	2.63(0.31)	0.63(0.10)	6.60(0.29)
		Mid	0.02(0.00)	0.59(0.01)	1.10(0.05)	7.13(0.05)
		Low	0.04(0.01)	0.88(0.08)	1.01(0.02)	7.22(0.20)
Log	NO	High	0.14(0.03)	2.29(0.20)	0.50(0.02)	6.86(0.13)
		Mid	0.07(0.01)	1.25(0.10)	0.64(0.09)	6.96(0.12)
		Low	0.09(0.01)	1.23(0.10)	0.62(0.03)	6.80(0.11)
Montz	CO	High	0.26(0.05)	3.88(0.44)	0.33(0.02)	6.13(0.07)
		Mid	0.03(0.01)	0.72(0.08)	0.90(0.04)	6.98(0.10)
		Low	0.06(0.02)	1.08(0.18)	0.90(0.02)	7.04(0.10)
Rodney	NY	Mid	0.03(0.02)	0.49(0.05)	1.08(0.04)	6.97(0.08)
	NI	Mid	0.02(0.00)	0.67(0.12)	1.10(0.05)	6.92(0.06)
Spoil	CI	Mid	0.10(0.03)	1.64(0.18)	0.52(0.03)	6.75(0.24)
Young	CY	High	0.00(0.00)	0.24(0.04)	1.24(0.06)	7.43(0.09)
		Mid	0.01(0.00)	0.26(0.03)	1.22(0.02)	7.66(0.08)
		Low	0.01(0.01)	0.39(0.03)	1.30(0.03)	6.81(0.28)

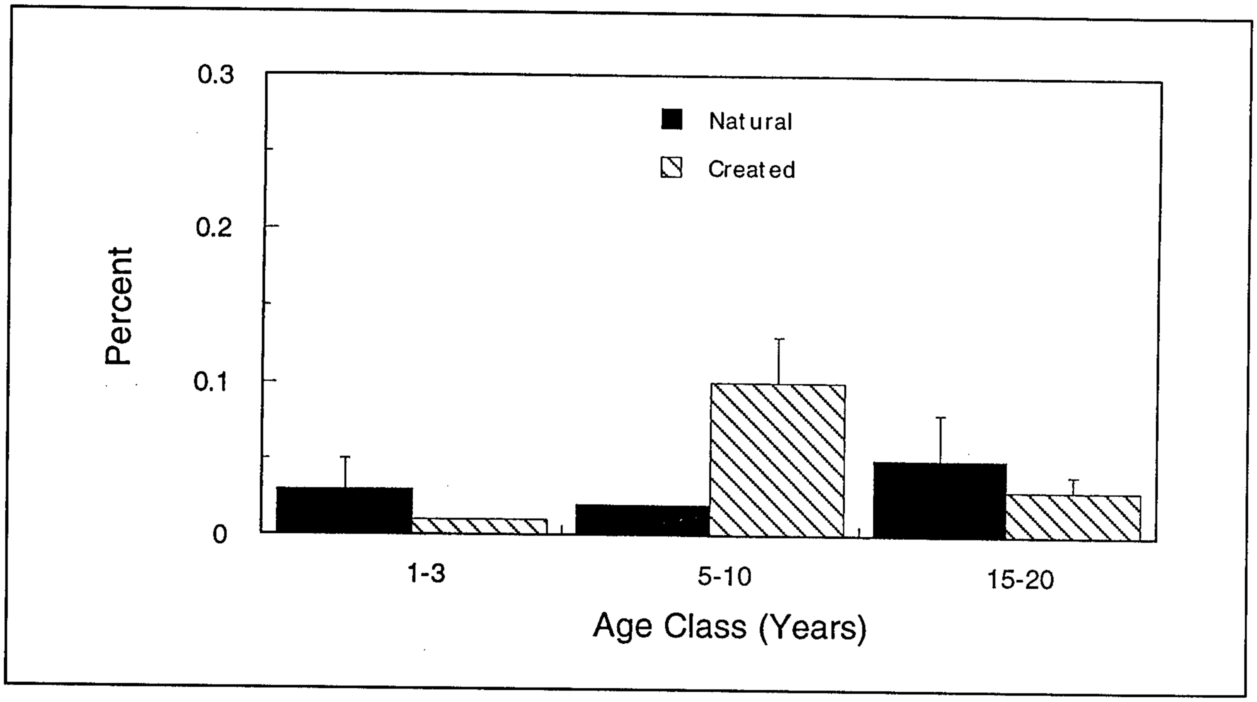

Figure 5. Total soil nitrogen of created and natural wetlands in the Atchafalaya Delta (mideleva- tion stratum)

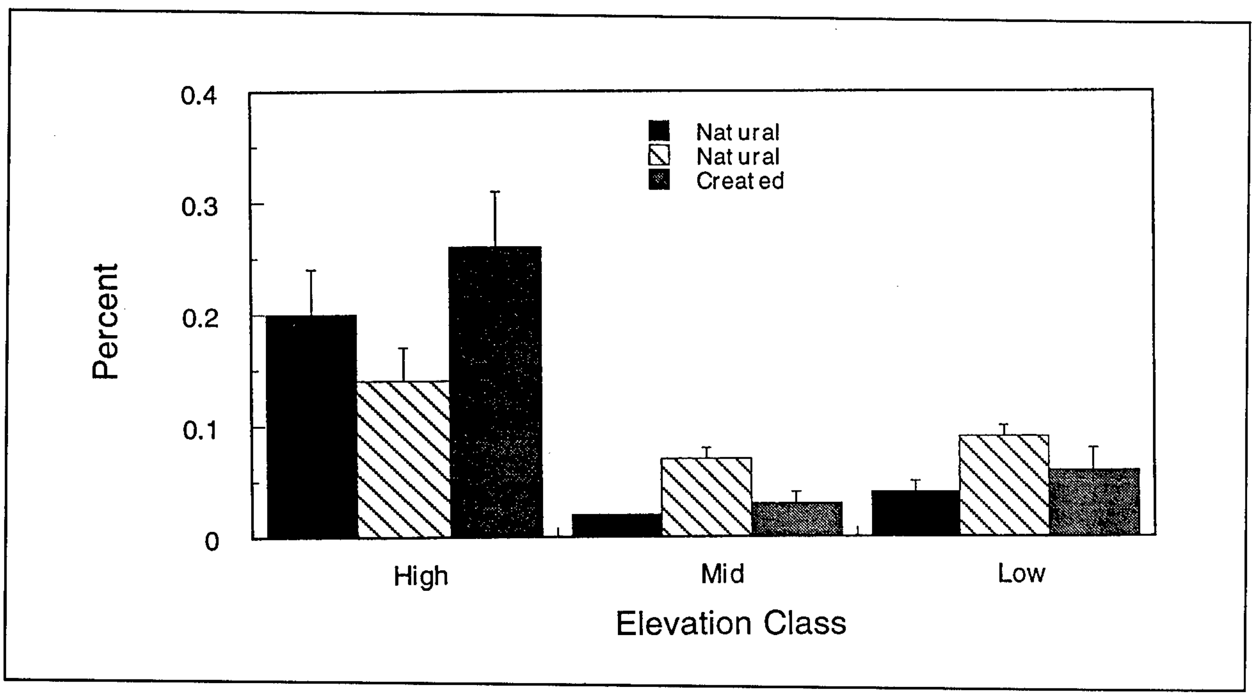

Figure 6. Total soil nitrogen of created and natural wetlands in the Atchafalaya Delta (old age class)

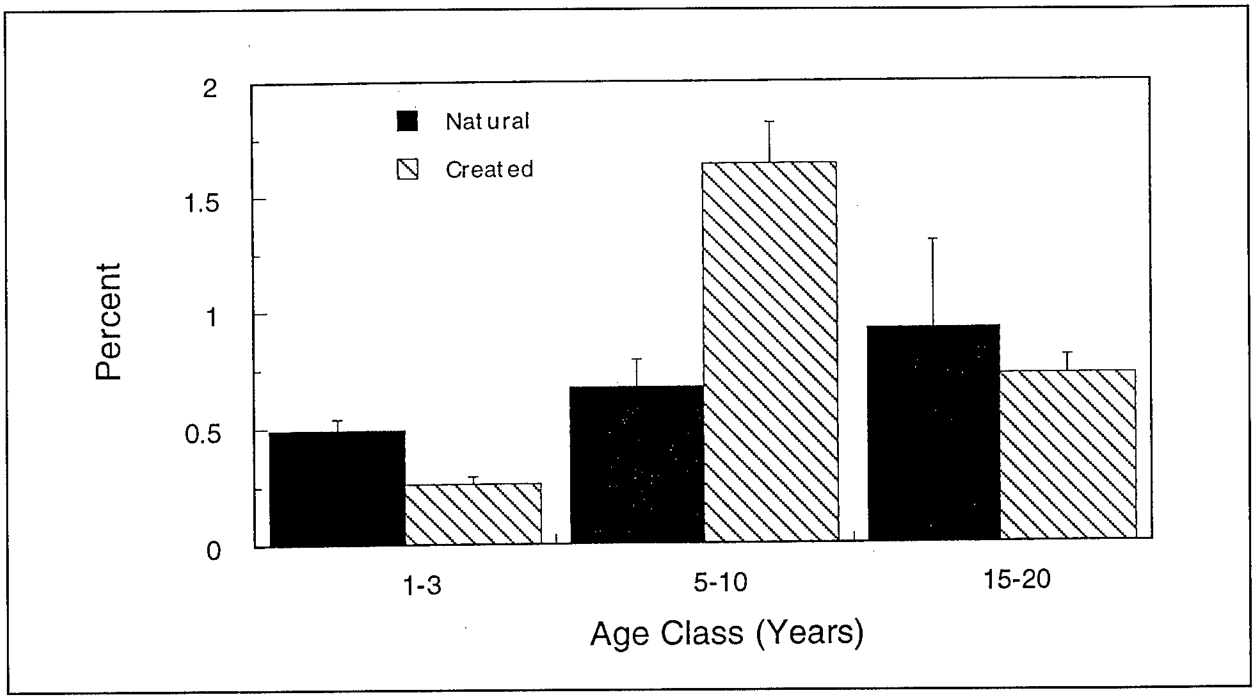

Figure 7. Total soil carbon of created and natural wetlands in the Atchafalaya Delta (midelevation stratum)

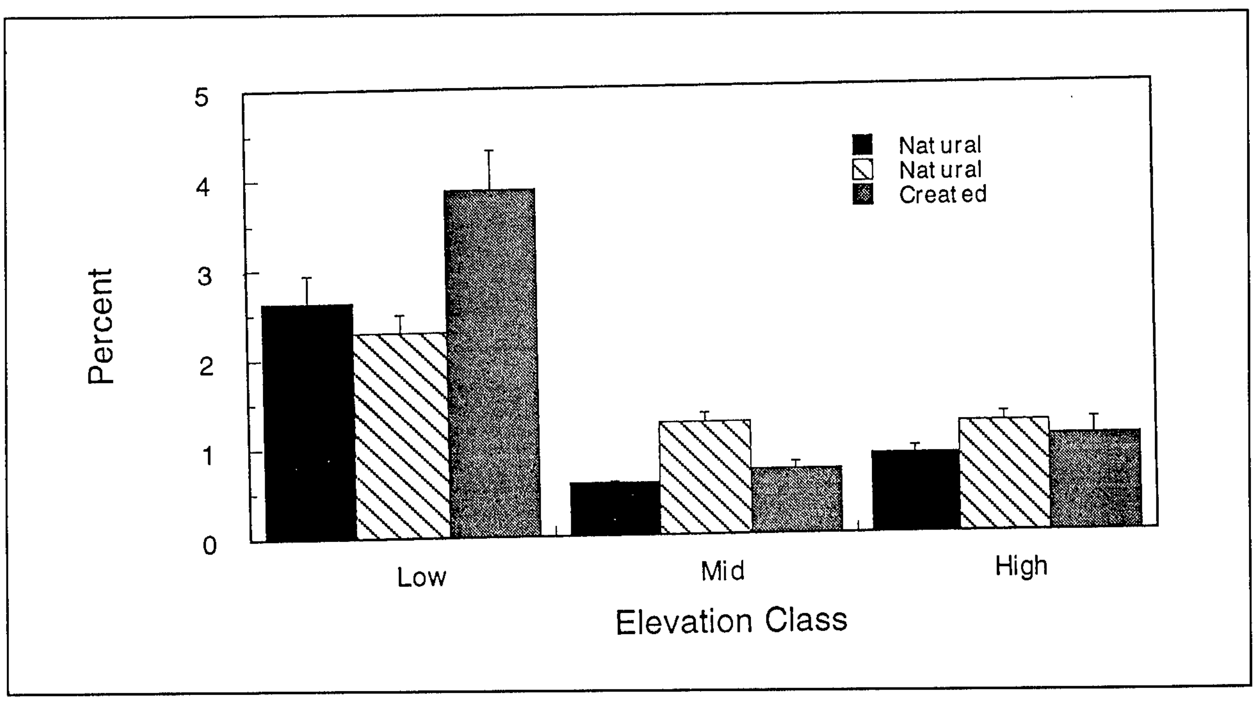

Figure 8. Total soil carbon of created and natural wetlands in the Atchafalaya Delta (old age class)

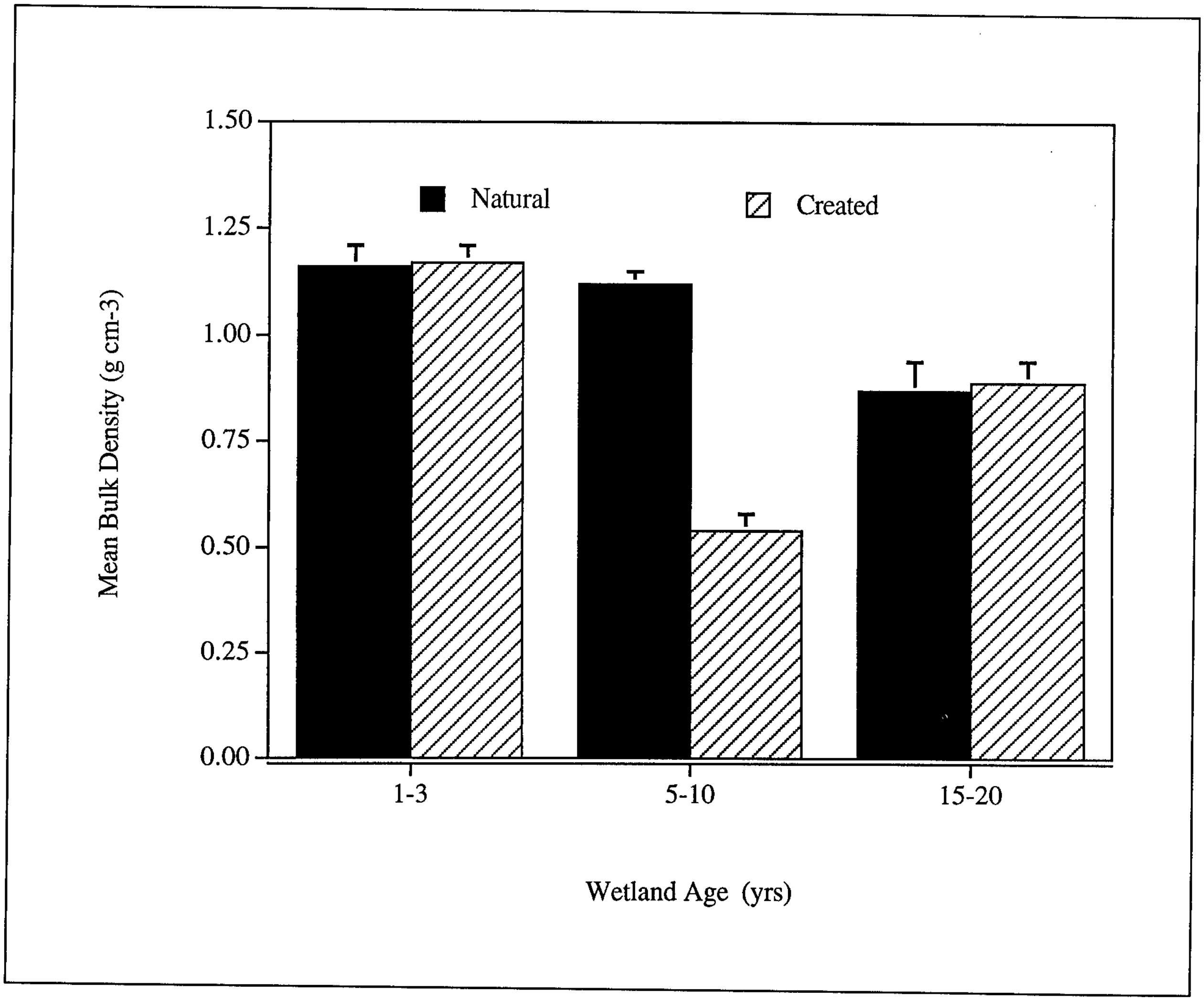

Figure 9. Soil bulk densities of created and natural wetland soils from midelevation sites (+1 se) in the Atchafalaya Delta

natural wetland soils (Figure 10). The CI soil had higher total P than the NI soil due to a higher organic P fraction in the CI soil (Figure 10). Except for the organic P fractions in November and January (Figures A4 and A14), the CY soil tended to have lower means for all the P fractions and total P than the NY soil. The means for the iron- and aluminum-bound and reductant-soluble fractions for the CY wetland did not always differ from the means for the NY wetland by their combined standard deviations (Figures A1, A2, A6, A7, A12, and A22). The CY wetland also tended to have lower soil P concentrations than the older wetlands, while CI and NI wetlands tended to have P concentrations similar to those of the old wetlands.

P concentrations in the CO soil were similar to concentrations in NO soils at low elevations but not at high elevations (Figure 11). Also in both CO and NO wetlands, P concentrations were greatest at the high elevation for all P forms except calcium-bound P, which was lowest at the high elevations

Table 3
Mean and Standard Deviation of Soil Phosphorus Fractions and Total Soil Phosphorus for Natural (N) and Created (C) Wetlands in the Atchafalaya Delta in November, 1993

Site[1]	Elevation	FE, Al-P μg/g Soil	RS-P μg/g Soil	Ca-P μg/g Soil	Total-P μg/g Soil	ORG. P μg/g Soil
N(15-20)	Low	94(32)	80(28)	305(19)	509(100)	31(28)
	Mid	48(2)	45(2)	309(25)	422(39)	20(15)
	High	220(63)	162(44)	275(33)	703(10)	46(15)
	Low	133(10)	136(39)	239(28)	567(61)	76(66)
	Mid	149(58)	101(26)	292(49)	613(106)	71(79)
	High	136(34)	85(86)	241(41)	612(25)	151(112)
C(15-20)	Low	105(26)	76(17)	285(18)	532(65)	66(27)
	Mid	62(27)	53(39)	308(32)	443(47)	19(22)
	High	106(31)	143(163)	225(48)	511(111)	107(178)
N(5-10)	Mid	78(25)	103(59)	293(75)	455(131)	0(0)
C(5-10)	Mid	116(9)	62(57)	266(19)	566(67)	123(92)
N(1-3)	Mid	82(15)	77(14)	239(1)	392(27)	0(0)
C(1-3)	Low	57(17)	40(23)	176(25)	259(29)	3(5)
	Mid	52(20)	21(34)	152(1)	262(43)	39(12)
	High	46(26)	5(8)	164(8)	227(17)	15(21)

Note: Standard deviation in parentheses with n = 3.
[1] Age in parentheses.

(Figures 10 and 11). For all elevations in the CY wetland, the lowest elevation tended to have the highest P concentrations (Figures 10 and 11).

Calcium-bound P was the dominant fraction for all sediments accounting for 33 to 67 percent of the total soil P while iron- and aluminum-bound and reductant-soluble P fractions accounted for 33 to 50 percent of total soil P (Tables 3 through 7). The organic P fraction was highly variable by season with high concentrations recorded in the December, May, and July samples (Tables 3 through 7). Organic P accounted for as much as 40 percent of the total soil P. These high concentrations were recorded in the CI wetland and at the high elevations in the old wetlands. When organic P was high, reductant-soluble P was low.

These results indicate that it takes from 10 to 20 years for the low and mid elevations of the created dredged material wetlands in the Atchafalaya Delta to develop soil P characteristics similar to those of their natural reference

Table 4
Mean and Standard Deviation of Soil Phosphorus Fractions and Total Soil Phosphorus for Natural (N) and Created (C) Wetlands in the Atchafalaya Delta in December, 1993

Site[1]	Elevation	FE, Al-P μg P/g Soil	RS-P μg P/g Soil	Ca-P μg P/g Soil	Total-P μg P/g Soil	ORG. P μg P/g Soil
N(15-20)	Low	79(15)	58(24)	319(13)	594(106)	138(103)
	Mid	48(19)	42(27)	290(12)	437(89)	57(32)
	High	208(54)	98(27)	252(59)	878(203)	320(115)
	Low[2]	115(26)	70(4)	299(72)	562(24)	77(66)
	Mid	119(50)	64(23)	274(52)	625(42)	168(38)
	High	94(9)	56(17)	249(33)	580(82)	181(30)
C(15-20)	Low	67(9)	44(1)	279(11)	523(68)	132(80)
	Mid	50(9.0)	31(6.1)	287(21.0)	517(140)	147(130)
	High	88(33)	52(19)	238(40)	588(62)	210(71)
N(5-10)	Mid	72(10)	35(4)	251(4)	470(42)	112(52)
C(5-10)	Mid	71(21)	48(11)	250(28)	559(45)	190(21)
N(1-3)	Mid	98(56)	38(11)	230(11)	432(51)	66(20)
C(1-3)	Low	49(22)	26(8)	173(22)	289(37)	41(9)
	Mid	36(24)	19(10)	152(4)	259(47)	52(31)
	High	28(13)	20(3)	151(3)	250(37)	52(33)

Note: Standard deviation in parentheses with n = 3.
[1] Age in parentheses.
[2] Natural, low site standard deviation has n = 2.

wetlands. Few studies have compared P pools in dredged material wetlands to those of natural wetlands. Lindau and Hossner (1981) reported that extractable P concentrations in a 2-year-old dredged material marsh were similar to those in two nearby natural marshes. It could be concluded from that study that dredged material wetlands can develop P pools similar to those of natural wetlands after only 2 years, but this may be true only for extractable P. Craft, Broome, and Seneca (1988) reported that a 13-year-old dredged-material marsh had lower total P than a nearby natural marsh even though the extractable P levels between the two were similar. Craft, Broome, and Seneca (1988) concluded that it would take longer than 30 years for soil nutrient pools in the created marsh to approximate those in the natural marsh. The difference between the natural and created marsh was attributed to the lack of organic matter development in the created marsh due to its younger age. As organic matter accumulates with time, the created marsh is expected to develop nutrient pools similar to those of the natural marsh. In the present

Table 5
Mean and Standard Deviation of Soil Phosphorus Fractions and Total Soil Phosphorus for Natural (N) and Created (C) Wetlands in the Atchafalaya Delta in January, 1994

Site[1]	Elevation	FE, Al-P μg/g Soil	RS-P μg/g Soil	Ca-P μg/g Soil	Total P μg/g Soil	ORG. P μg/g Soil
N(15-20)	Low	88(22)	55(29)	311(22)	489(9)	35(22)
	Mid	56(31)	39(17)	305(5)	441(63)	41(13)
	High	263(59)	216(150)	260(18)	813(156)	74(36)
	Low[2]	116(15)	50(2)	252(1)	491(23)	73(12)
	Mid	99(22)	65(8)	308(43)	503(29)	31(9)
	High	101(25)	76(53)	251(34)	496(57)	68(57)
C(15-20)	Low	65(10)	46(8)	261(15)	417(67)	46(38)
	Mid	61(16)	19(16)	342(24)	473(60)	52(18)
	High	121(31)	87(31)	213(7)	560(75)	139(22)
N(5-10)	Mid	84(2)	36(8)	244(12)	394(16)	30(8)
C(5-10)	Mid	113(31)	77(15)	249(17)	517(90)	79(45)
N(1-3)	Mid	93(24)	43(38)	233(37)	417(104)	49(21)
C(1-3)	Low	61(24)	38(36)	174(19)	273(46)	9(14)
	Mid	30(8)	6(10)	153(9)	238(24)	49(28)
	High	32(11)	16(27)	160(7)	234(8)	28(24)

Note: Standard deviation in parentheses with n = 3.
[1] Age in parentheses.
[2] Natural, low site standard deviation has n = 2.

study, the created wetland soils also had low organic matter content, but at mid and low elevations the created wetland soil took less than 20 years to develop P characteristics similar to those of a natural wetland soil. In another study, a 2-year-old tidal, freshwater marsh created from dredged material was reported to have a total soil P concentration that was similar to a nearby natural marsh (Adams 1978). The range of total soil P (648 to 814 μg/g P) and percent organic matter for that study were comparable to the values from the older wetlands in the present study.

The difference between conclusions reached by this study and Adams (1978) and the conclusions of Craft, Broome, and Seneca (1988) could be explained by the fact that the former studies were conducted on river-dominated systems. Sediment deposition due to the flooding river appears to be the major factor controlling P dynamics and wetland development in the delta. Johnson, Sasser, and Gosselink (1985) found that total soil P of some of the natural islands in the Atchafalaya Delta varied little spatially or

Table 6
Mean and Standard Deviation of Soil Phosphorus Fractions and Total Soil Phosphorus for Natural (N) and Created (C) Wetlands in the Atchafalaya Delta in May, 1994

Site[1]	Elevation	FE, Al-P μg P/g Soil	RS-P μg P/g Soil	Ca-P μg P/g Soil	Total P μg P/g Soil	ORG P μg P/g Soil
N(15-20)	Low	96(17)	36(39)	280(23)	536(64)	125(31)
	Mid	49(11)	24(11)	331(20)	441(44)	42(37)
	High	359(135)	159(72)	274(22)	971(308)	180(107)
	Low	96(24)	24(10)	295(41)	549(44)	133(27)
	Mid	140(20)	73(17)	280(19)	638(72)	145(64)
	High	119(32)	66(39)	254(29)	596(91)	157(41)
C(15-20)	Low	60(4)	27(9)	287(30)	450(15)	77(36)
	Mid	49(16)	19(7)	317(53)	496(85)	111(27)
	High	109(36)	29(1)	220(36)	573(30)	215(20)
N(5-10)	Mid	81(31)	37(14)	231(13)	439(45)	89(51)
C(5-10)	Mid	112(8)	30(7)	221(10)	572(19)	208(24)
N(1-3)	Mid	75(8)	39(9)	252(22)	469(29)	103(13)
C(1-3)	Low	55(25)	24(8)	170(26)	281(35)	31(12)
	Mid	25(5)	16(5)	155(4)	238(17)	41(12)
	High	46(16)	36(20)	180(21)	262(39)	10(9)

Note: Standard deviation in parentheses with n = 3.
[1] Age in parentheses.

temporally. They attributed this homogeneity to the spring flooding of the river and the sedimentation associated with it.

This periodic sedimentation would explain the development of natural P characteristics by the created wetlands in the present study. The created wetlands are originally formed from bed-load sediment while the natural wetlands are formed from suspended sediment. The fact that the CY soil is lower in P than the NY soil would indicate that the bed-load sediment is lower in P than the suspended sediment. The CI and CO soils have P concentrations similar to their natural counterparts because they are old enough for flooding to have deposited similar suspended sediment on them. The bed-load sediment is lower in P than the suspended sediment because the bed-load sediment is coarser grained as indicated by the higher sand content of the CY soil compared with the other wetland soils (Figure 12). Phosphorus is associated more with silt and clay than with sand (Syers, Shah, and Walker 1969). It is likely that if the bed-load sediment used to form the dredged material islands had the

Table 7
Mean and Standard Deviation of Soil Phosphorus Fractions and Total Soil Phosphorus for Natural (N) and Created (C) Wetlands in the Atchafalaya Delta in July, 1994

Site[1]	Elevation	FE, Al-P μg P/g Soil	RS-P μg P/g Soil	Ca-P μg P/g Soil	Total P μg P/g Soil	ORG. P μg P/g Soil
N(15-20)	Low	97(28)	57(32)	281(10)	590(58)	155(10)
	Mid	47(13)	20(10)	332(49)	513(63)	113(22)
	High	316(114)	155(78)	255(18)	1,101(367)	376(199)
	Low	120(31)	35(14)	260(6)	533(23)	118(21)
	Mid	120(25)	45(15)	307(98)	610(70)	138(64)
	High	126(7)	38(6)	298(71)	621(37)	160(94)
C(15-20)	Low	74(14)	27(3)	299(20)	520(15)	121(2)
	Mid	89(25)	31(5)	327(20)	577(97)	129(70)
	High	114(25)	27(14)	209(69)	548(131)	199(41)
N(5-10)	Mid	146(66)	49(27)	240(7)	559(135)	124(55)
C(5-10)	Mid	99(3)	30(2)	218(23)	571(78)	225(73)
N(1-3)	Mid	78(17)	27(7)	227(21)	437(56)	105(13)
C(1-3)	Low	50(1)	19(5)	187(30)	345(37)	88(14)
	Mid	40(16)	25(8)	163(22)	293(17)	66(14)
	High	25(8)	17(7)	155(18)	264(31)	67(2)

Note: Standard deviation in parentheses with n = 3.
[1] Age in parentheses.

same clay/silt content as the suspended sediment, then the P characteristics of the created and natural wetlands would be similar. This would explain the similarity between the created and natural marshes reported by Adams (1978).

At low and mid elevations, the CO wetland in the present study and the NO wetlands had similar P concentrations. However, if these concentrations were compared with the literature data from other natural, tidal freshwater marshes, then the created wetland would not be considered to be similar to natural wetlands. Total soil P concentrations in the present study were lower than those reported for other natural, tidal freshwater marshes (Simpson et al. 1983; Bowden 1984). Simpson et al. (1983) reported values from 1,200 to 1,700 ppm P for two mineral marshes while Bowden (1984) reported values from 2,000 to 3,000 ppm P in the top 10 cm of marsh. These marshes are older in terms of successional age as indicated by the fact that they have organic matter contents from 14 to 75 percent (Odum et al. 1984), which are

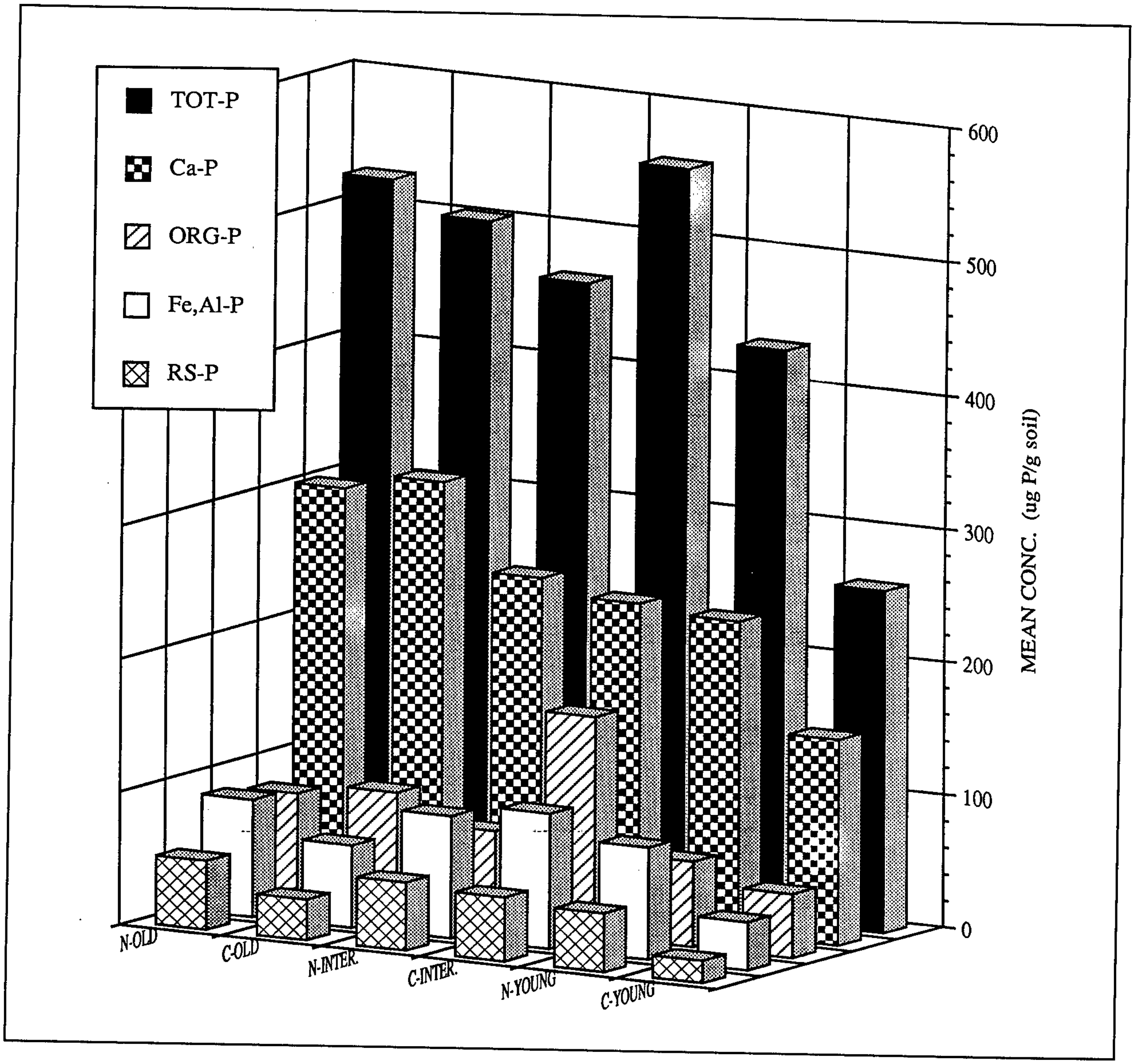

Figure 10. Phosphorus forms and their mean concentrations found in natural (N) and created (C) wetland soils in the Atchafalaya Delta (midelevation sites)

higher than recorded in the wetlands of this study. The fact that a wetland has an accumulation of organic material would suggest that its succession is partially controlled by autogenic processes. Nutrient pools are, therefore, able to increase with the development of the marsh. The wetlands in this study, however, were controlled mostly by allogenic processes (Shaffer et al. 1992). Therefore, succession was held to an early stage.

The accumulation of organic matter at the high elevation sites of the old wetlands indicated that they were at least partially controlled by autogenic processes. In the old wetlands, the higher elevation tended to have higher P concentrations in all except the calcium-bound P than the lower elevation because

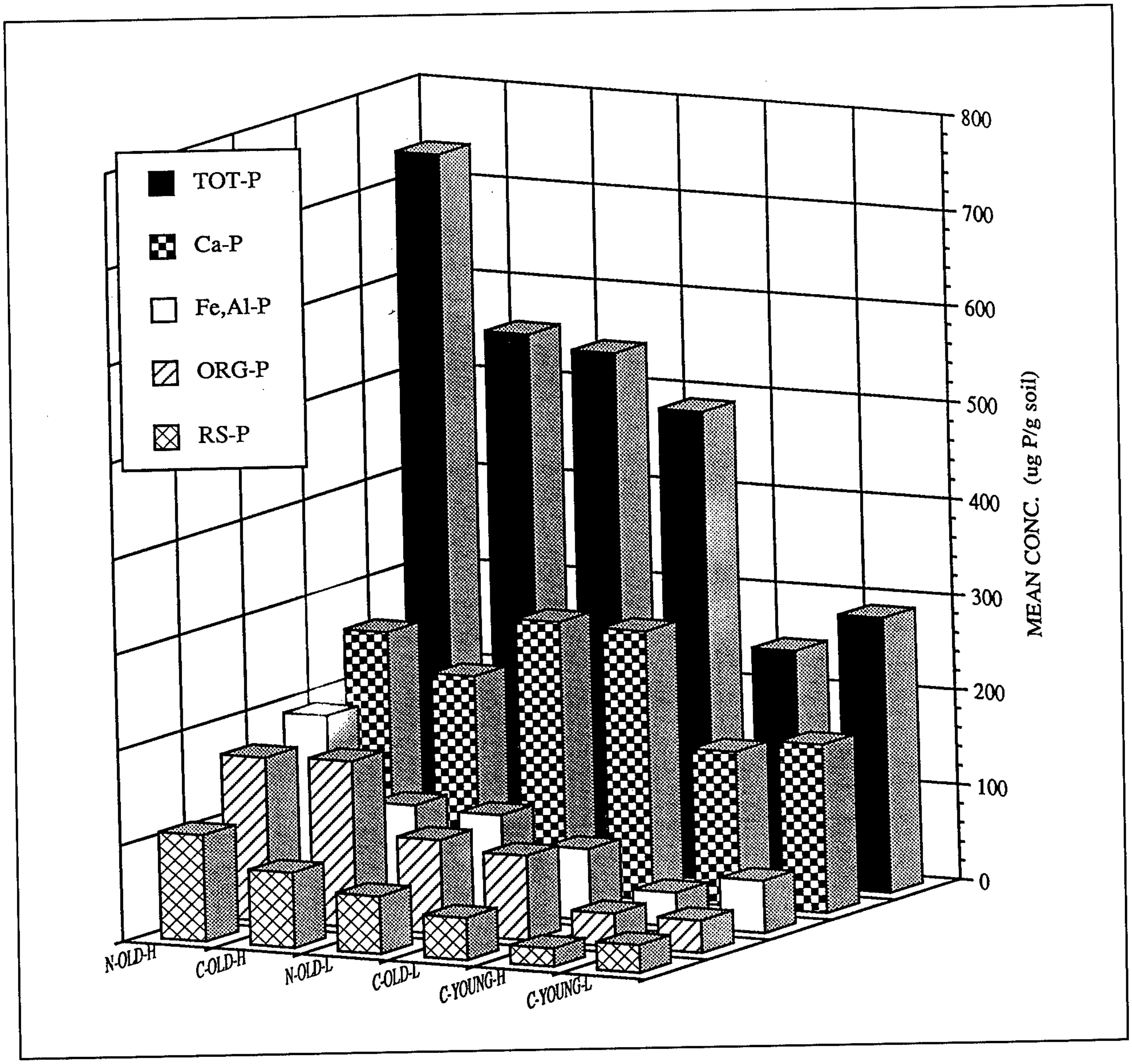

Figure 11. Phosphorus forms and their mean concentrations at low (L) and high (H) elevation sites of natural (N) and created (C) wetlands in the Atchafalaya Delta

it was flooded to a lesser degree by the river. Less flooding means that less mineral matter (mainly calcium-bound P) is deposited at the high sites and less organic matter is washed away by the floodwaters. Therefore, there is a greater accumulation of organic matter at the high sites than at the low sites. The lower accumulation of mineral matter could explain why the high sites of the CO wetland are not similar to the high sites of the NO wetlands after 20 years.

The CI wetland also had higher total P due to a higher organic matter accumulation than in the NI wetland. Organic matter was able to accumulate at the created site due to a berm present at the riverside edge of the marsh.

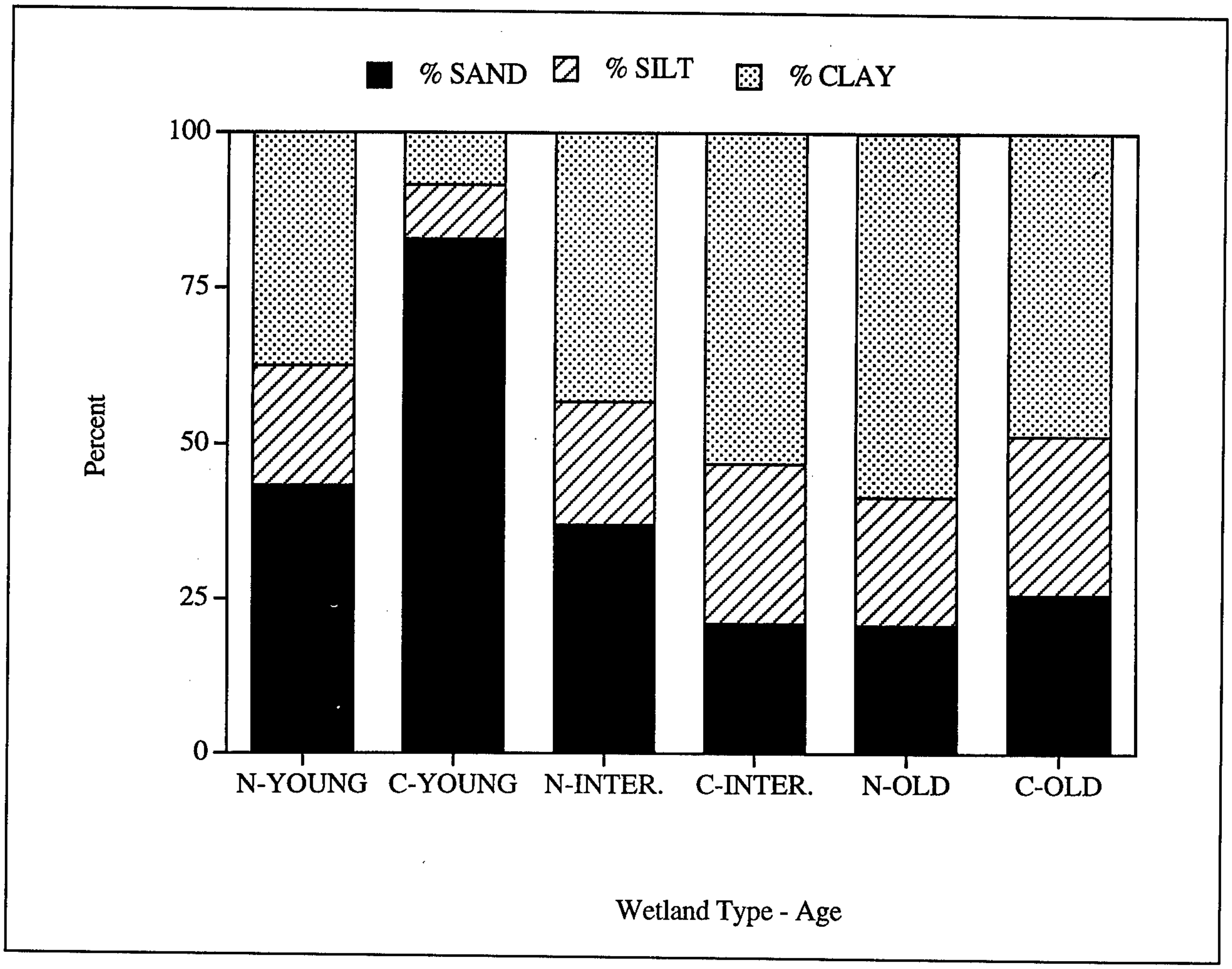

Figure 12. Sediment particle size of natural (N) and created (C) wetland soils in the Atchafalaya Delta (midelevation sites)

This berm caused floodwaters to pond behind it, thereby resulting in the almost permanent flooding of the plots at this site. The accumulation of organic matter at this site compared with its natural reference site resulted in higher organic P and lower bulk density measurements for this site. This has important implications for the development of natural P characteristics by the created wetland. If only total P on a weight basis was considered, then it might be concluded that it takes only from 5 to 10 years for a created marsh to develop natural P characteristics (Figure 10). However, since the CI soil has a lower bulk density than the NI soil, the CI soil has less P per area (Figure 13). Therefore, on an area basis, it takes from 10 to 20 years for created wetlands to develop natural P levels. If the berm were not present at the CI wetland, then more mineral matter could have been deposited by floodwaters and less organic matter could have accumulated due to less ponding. An increase in mineral matter and a decrease in organic matter would increase the bulk density of the CI soil. If the berm were not present, then the CI wetland could have the same P on an area basis as the NI wetland. Therefore, in the

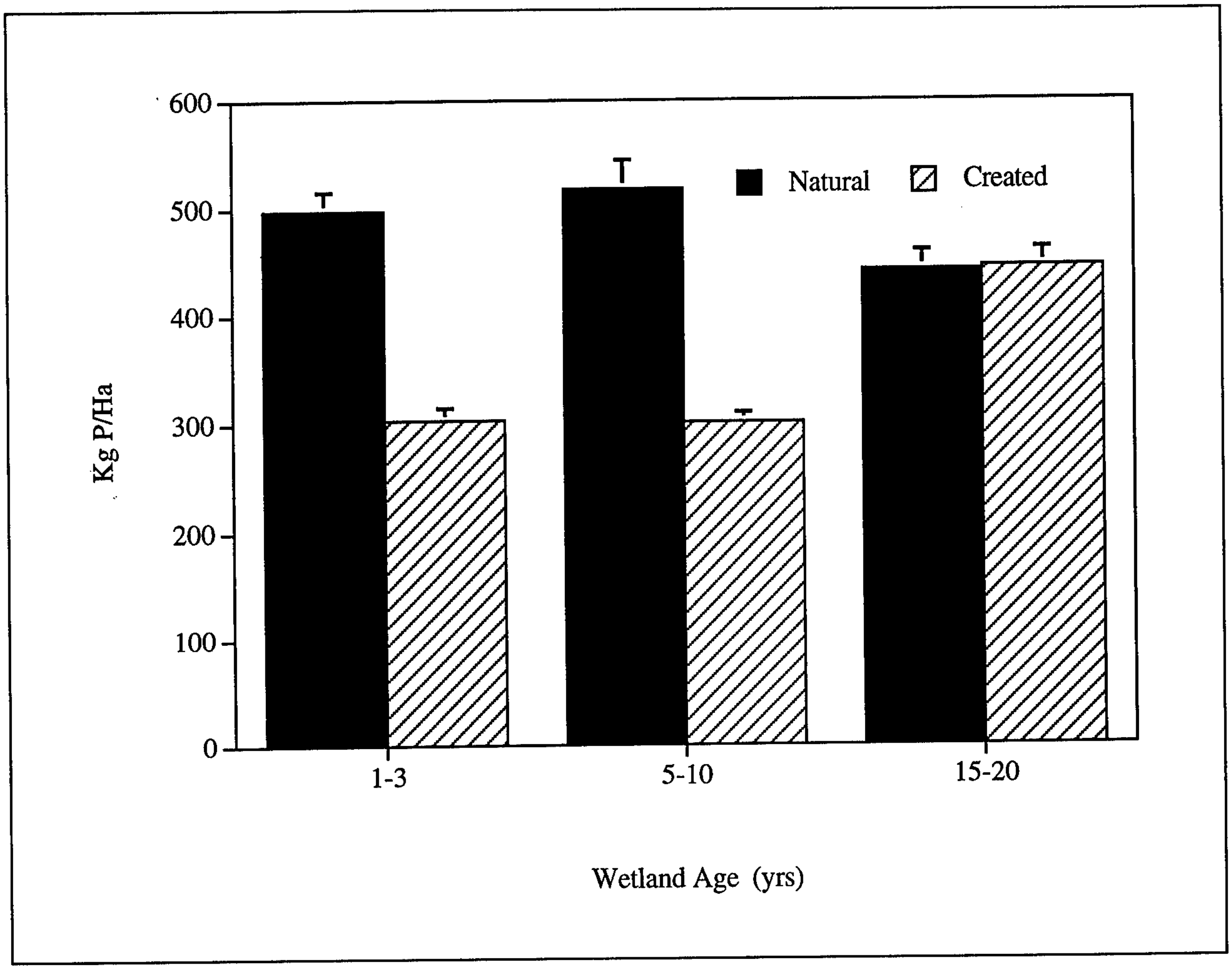

Figure 13. Comparison of mean (+ sd) total soil phosphorus per area for natural and created wetlands in the Atchafalaya Delta (midelevation sites)

Atchafalaya Delta, it could actually take less than 10 years for a created wetland to develop natural P characteristics if it is graded properly.

Calcium-bound P would be expected to be the dominant form in wetland soils in this study due to the soil pH. Calcium phosphate tends to precipitate under alkaline conditions while iron and aluminum phosphate tend to precipitate under acid conditions (Stevenson 1986). However, the alkalinity of the sediment and the abundance of calcium-bound P may be the result of minimal weathering of the wetland sediment. It is likely that the sediment carried by the river would have undergone mainly physical weathering due to erosion. This sediment would, therefore, contain mainly primary minerals. P associated with primary minerals is solubilized by the acid extraction and is considered to be calcium phosphate. Therefore, the high calcium-bound P in wetland soils in this study may be the result of a high primary mineral content.

The variability in the organic P data is due to the procedure used to calculate it. P in the CBD extract was most likely overestimated in November 1993 and January 1994 samples due to interferences with P determination. Overestimation in the reductant-soluble P would lead to underestimation of organic P.

Phosphate accumulation on the resin bags varied both seasonally and among the different wetlands. Phosphate concentrations were generally highest in the spring and lowest in the summer at all sites (Figure 14). The lowest phosphate concentrations were measured at the CY wetland and were lower than those of the NY wetland (Figure 14a). Phosphate levels were similar between CI and NI and between CO and NO (Figures 14b and c); however, some variation was observed in the NO wetlands with generally higher concentrations at Log Island (Figure 14c).

There were distinct elevational differences at those sites with different strata, although no consistent patterns were evident. Within the old age class, phosphate concentrations at Gary's Island were greatest at the high elevation while just the opposite occurred at Log Island and Montz Island (Table 8). Some resin bags could not be found or measured (due to nutria damage) and caused the missing data at the low elevations at Log and Montz. There was a clear pattern of increasing phosphate concentration with lower elevation in the CY wetland (Table 8).

Nitrogen

N mineralization rates displayed a strong seasonal pattern. A low N mineralization rate of less than 5 g m^{-2} $year^{-1}$ was observed only in the summer in the CY wetland with net immobilization occurring the rest of the year (Figure 15). The NY wetland had N mineralization rates in excess of 25 g m^{-2} $year^{-1}$ in the spring and summer with much lower rates in fall and winter. Both CI and NI wetlands had little or no net N mineralization in fall and winter with similar rates in spring and summer (Figure 16). The same seasonal pattern was evident in the CO and NO wetlands although mineralization rates were generally higher than the young and intermediately aged wetlands in the fall and winter (Figure 17).

Overall, DEA was lowest in both CY and NY wetlands and highest in the CI wetland (Figure 18). DEA was comparable between created and natural wetlands in all three age classes. The only seasonal pattern evident was an increase in DEA in the fall. This was particularly pronounced in the old age class (Figure 18c). This result, in combination with the consistently high DEA levels in the CI wetland, suggests that carbon availability is an important factor regulating DEA levels in these wetlands. The CI wetland had nearly twice the soil carbon content of the other wetlands. The importance of carbon in denitrification has been well documented (Reddy, Rao, and Jessup 1982; Myrold 1988; Christensen, Simkins, and Tiedje 1990; Groffman 1994). The high DEA values measured during the summer sampling period for the CO

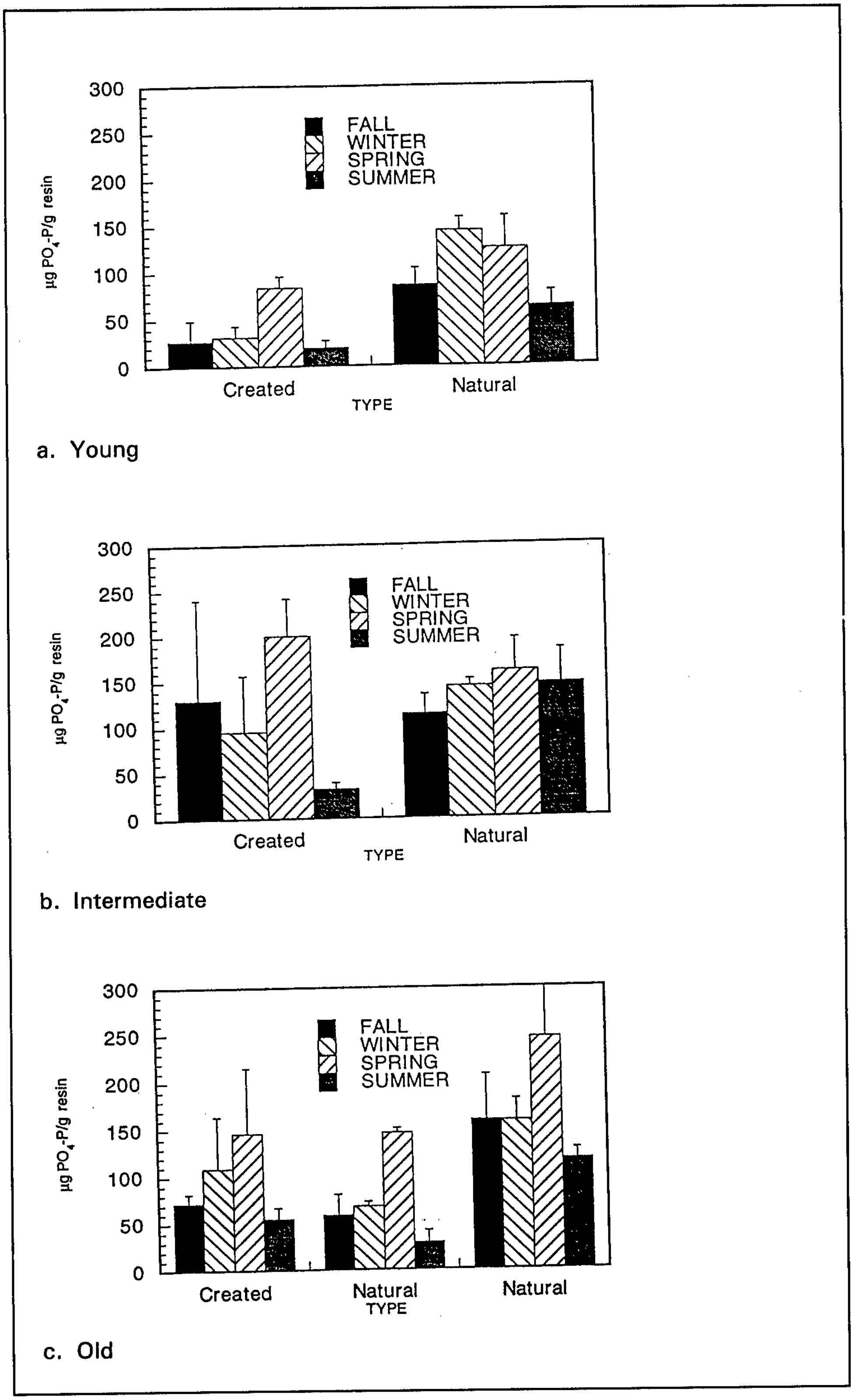

Figure 14. Mean (+1 sd) P concentrations on anion exchange resin bags in young, intermediate, and old created and natural wetlands in the Atchafalaya Delta (midelevation stratum)

Table 8
Mean ($\pm$ se) Phosphate Concentration on Resin Bags from Created and Natural Wetland Study Sites in the Atchafalaya Delta

Site	Type	Elevation	$\mu g\ PO_4\ g^{-1}$ Resin			
			Fall	Winter	Spring	Summer
Gary	NO	High	328(199)	91(9)	329(215)	170(137)
		Mid	59(22)	68(5)	146(5.0)	29(13)
		Low	45(8)	65(27)	61(22.8)	40(23)
Log	NO	High	164(86)	44(15)	125(28)	69(26)
		Mid	159(48)	158(23)	246(110)	117(11)
		Low	131(68)	355(282)	221(39)	--[1]
Montz	CO	High	125(99)	62(20)	132(63.6)	27(9)
		Mid	72(10)	109(55)	146(69.5)	55(12)
		Low	118(34)	137(3)	--[1]	--[1]
Rodney	NY	Mid	86(18)	143(8)	160(36.4)	146(38)
	NI	Mid	114(21)	95(62)	200(42.1)	32(7)
Spoil	CI	Mid	130(111)	144(14)	125(34.7)	63(16)
Young	CY	High	5(2)	25(17)	47(36.1)	14(8)
		Mid	27(22)	31(12)	84(12.9)	19(8)
		Low	118(77)	65(21)	156(74.7)	45(21)

[1] Resin bag could not be found or measured due to nutria damage.

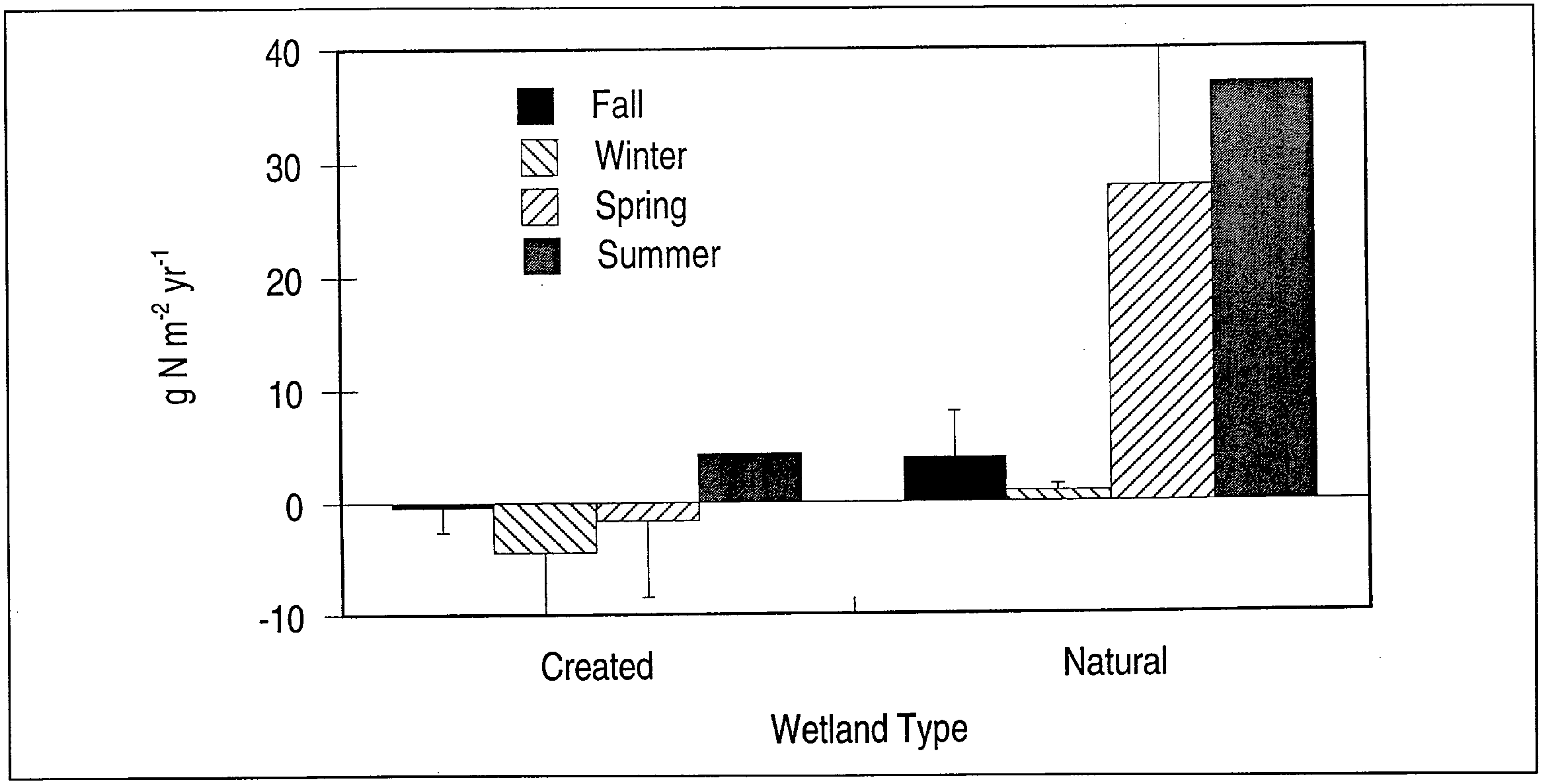

Figure 15. Mean (+1 sd) annual N mineralization rates of young created and natural wetlands in the Atchafalaya Delta (midelevation stratum)

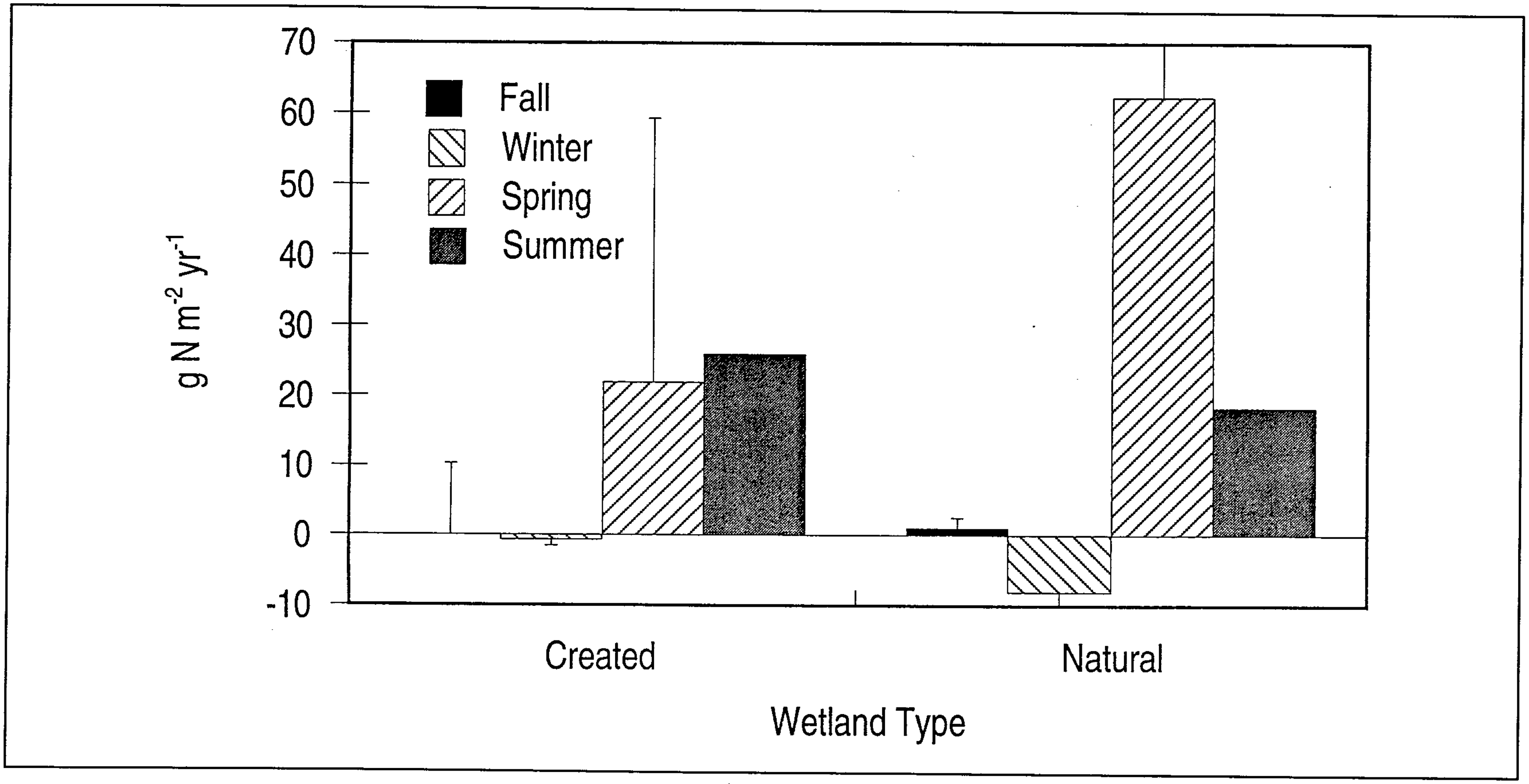

Figure 16. Mean (+1 sd) annual N mineralization rates of intermediate created and natural wetlands in the Atchafalaya Delta (midelevation stratum)

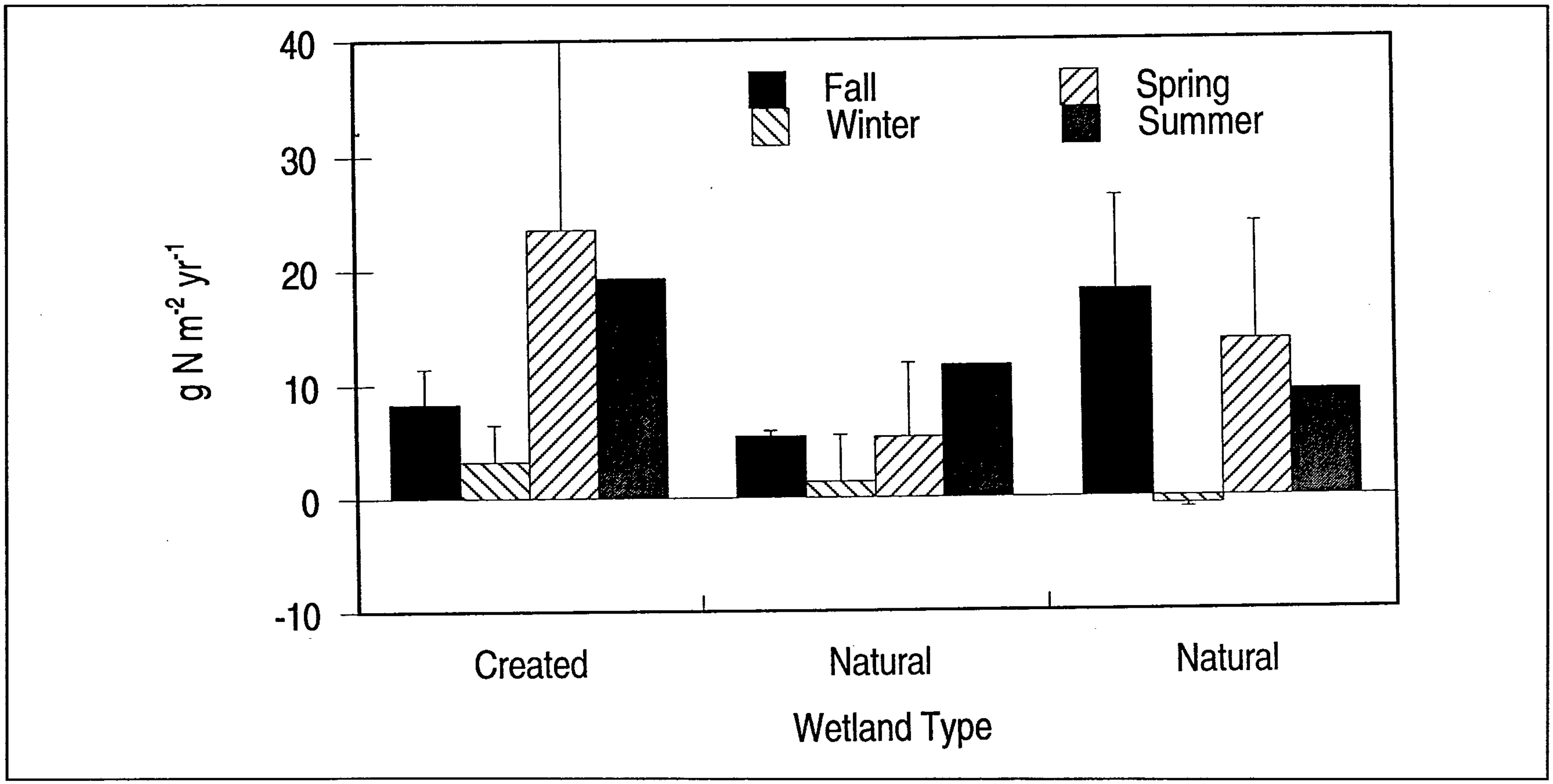

Figure 17. Mean (+1 sd) annual N mineralization rates of old created and natural wetlands in the Atchafalaya Delta (midelevation stratum)

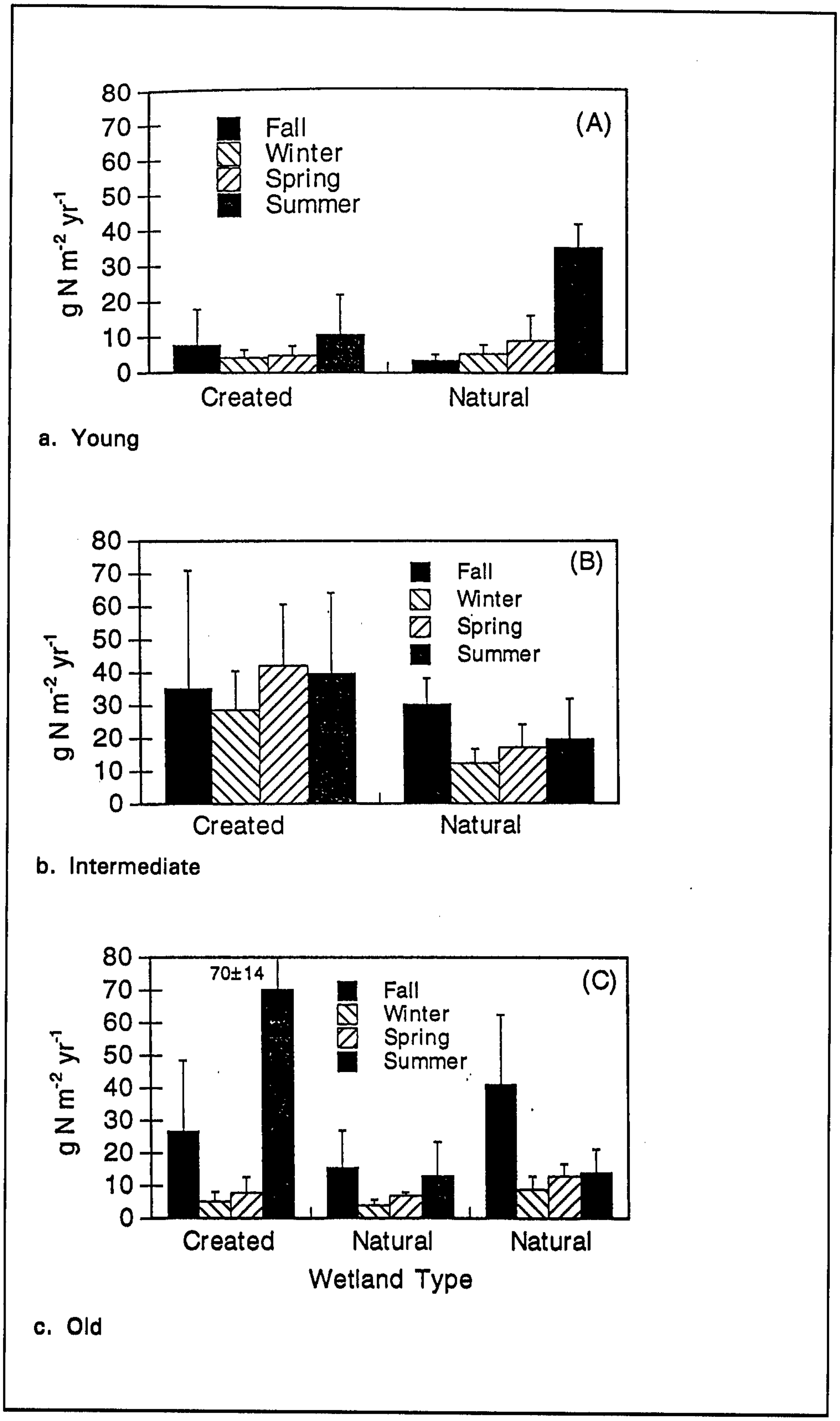

Figure 18. DEA for created and natural wetlands in the Atchafalaya Delta (mean +1 sd, midelevation stratum)

wetland were likely due to localized areas of intense denitrification known as "hotspots" (Parkin 1987; van Kessel, Pennock, and Farrell 1993).

Comparing the DEA results (Figure 18) with the N mineralization rates (Figure 15-17) suggests that the estimated N losses through denitrification are offset to a large extent by N mineralization. Given other nitrate inputs into the ecosystem from the atmosphere and the Atchafalaya River, the estimates of N loss through denitrification do not appear out of balance with the overall cycling of N through the system. However, more work is needed to accurately estimate the total N cycle for these wetlands.

Vegetation

A total of 53 species were found on the natural and created wetlands (Appendix B). Twin-span analysis of the vegetation data indicated a clear separation of the wetlands. The first level of separation made the obvious distinction between the unvegetated mud flats and the vegetated strata (Figure 19). Within the vegetated strata, the old wetlands were distinguished from the young wetlands by the dominance of *Colocasia antigorum* and *Polygonum punctatum* on the former. Finally, the NY wetland was characterized by a monotypic stand of *Scirpus americanus* while *Panicum virgatum*, *Ammania coccinea*, and *Cyperus oderatus* were present on the CY wetland (Figure 19). This difference in species composition between the CY and NY wetlands is

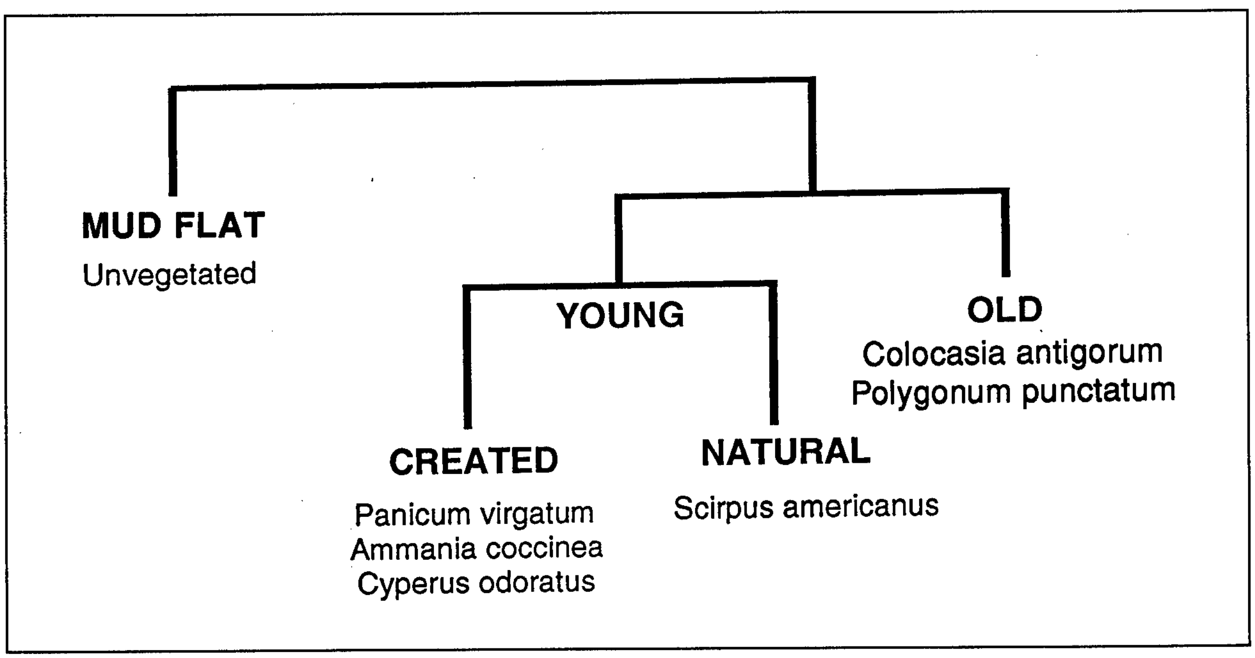

Figure 19. Twin-span analysis of vegetation on created and natural wetlands of the Atchafalaya Delta, Louisiana

directly attributable to the elevational characteristics with the greater species diversity on the different elevations present on the CY wetland.

Total aboveground biomass was much lower on the CY although the data in Figure 20 do not clearly show this difference. The large error associated with the aboveground biomass on the NY wetland was due to herbivory by nutria (*Myocastor coypus*) on some of the vegetation subplots. This impact on the natural vegetation of the Atchafalaya Delta has been documented by previous work (Fuller et al. 1985). In addition, the results for the CO and NO wetlands in Figure 20 are lowered by the absence of biomass data for the tree species *Salix nigra* which accounts for 16 to 26 percent of the total cover on these wetlands. Given the greater density of woody vegetation, this is a significant component of the total aboveground biomass. However, the authors did not want to damage the sites by destructively sampling the *Salix* community to obtain accurate estimates.

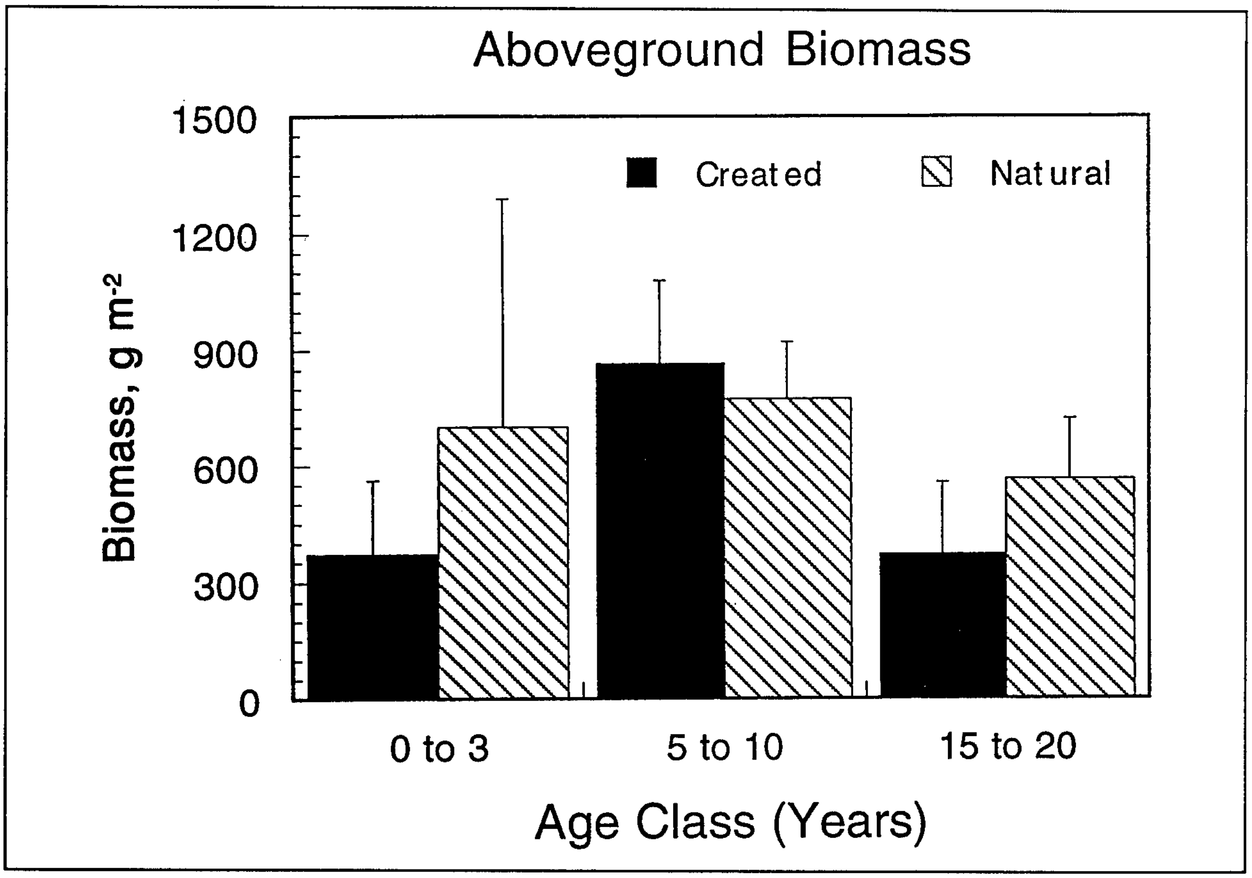

Figure 20. Mean (+1 sd) aboveground biomass of natural and created wetlands in the Atchafalaya Delta

Summary Relationships

It is desirable to synthesize the physical and chemical attributes of the natural and created wetlands to provide a coherent framework from which relationships among the different variables can be inferred. Gradient analysis is a useful technique for determining these relationships and has been used primarily to determine plant community response to various environmental gradients (e.g., moisture, nutrients). Canonical correspondence analysis is a particularly appropriate technique since it directly relates individual plots (in this case, the elevational strata within the individual wetlands) to the suite of environmental variables and identifies the most important variables through a statistical paradigm (Ter Braak 1986). This approach is an extension of the widely used correspondence analysis (Hill and Gauch 1980; Gauch 1982).

The results of this analysis are shown in Figure 21. The environmental variables that best explain the distribution of the plots are total P, organic matter content (OM), and bulk density (BD). The gradients of these three variables are designated by the bold arrow showing the direction of the gradient, and the importance of the variable is represented by the length of the arrow. Only vegetated plots were used in this analysis since an initial iteration with all the plots simply segregated the unvegetated mud flats from the vegetated plots. In addition to the mid- and high-elevation plots, the low-elevation plots from the young created wetland (CY-LO) and one of the old natural wetlands (NO2-LO) were included because of the presence of vegetation.

The canonical correspondence analysis clearly separates the CY wetland from the rest of the plots and identifies this wetland with high bulk densities and low total P and organic matter (Figure 21). This is consistent with the other results discussed previously and confirms the CY wetland as both structurally and functionally distinct from the other sites. The NY and NI wetlands were also spatially distinct from the other plots due to their higher bulk density and lower total P content. They were distinguished from the CY wetland by their higher organic matter content. The remaining created and natural wetlands were closely clustered indicating few differences between these two categories.

Canonical correspondence analysis also clearly distinguishes the vegetation found on the CY wetland from the other species. *P. virgatum*, *A. coccinea*, and *C. oderatus* dominate the sites with high bulk densities and low total P and organic matter (Figure 22). The other species associated with young wetlands, *S. americanus*, and *Cyperus difformis*, showed a similar affinity for soils with high bulk densities and low total P, but higher in organic matter.

The results of the canonical correspondence analysis are consistent with the other chemical and physical data indicating that, even after 3 years, created and natural wetlands are generally dissimilar. It takes 5 to 10 years for the structural attributes of created wetlands to approach those of natural wetlands.

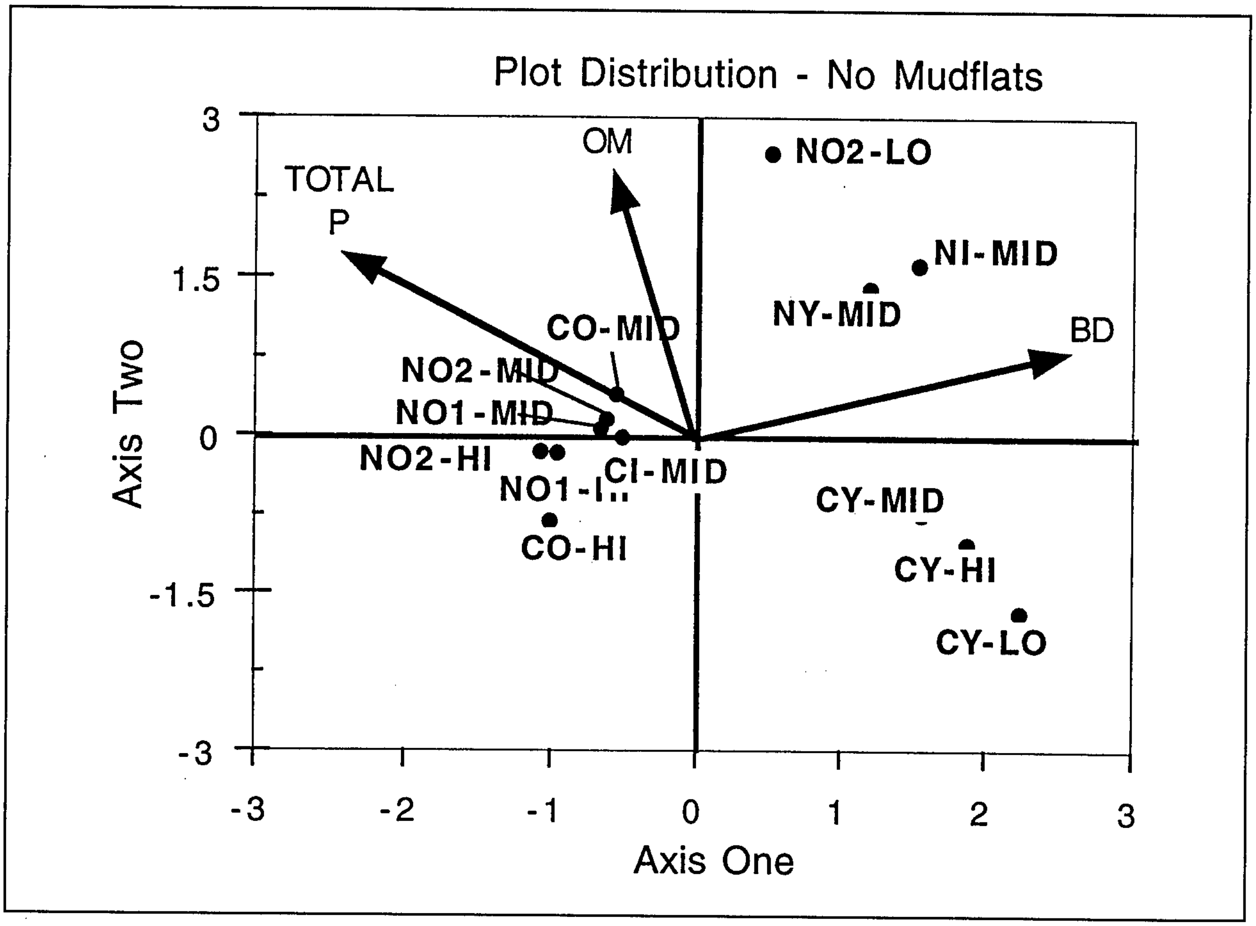

Figure 21. Canonical correspondence analysis of created and natural wetland plots in the Atchafalaya Delta (excluding nonvegetated mud flats)

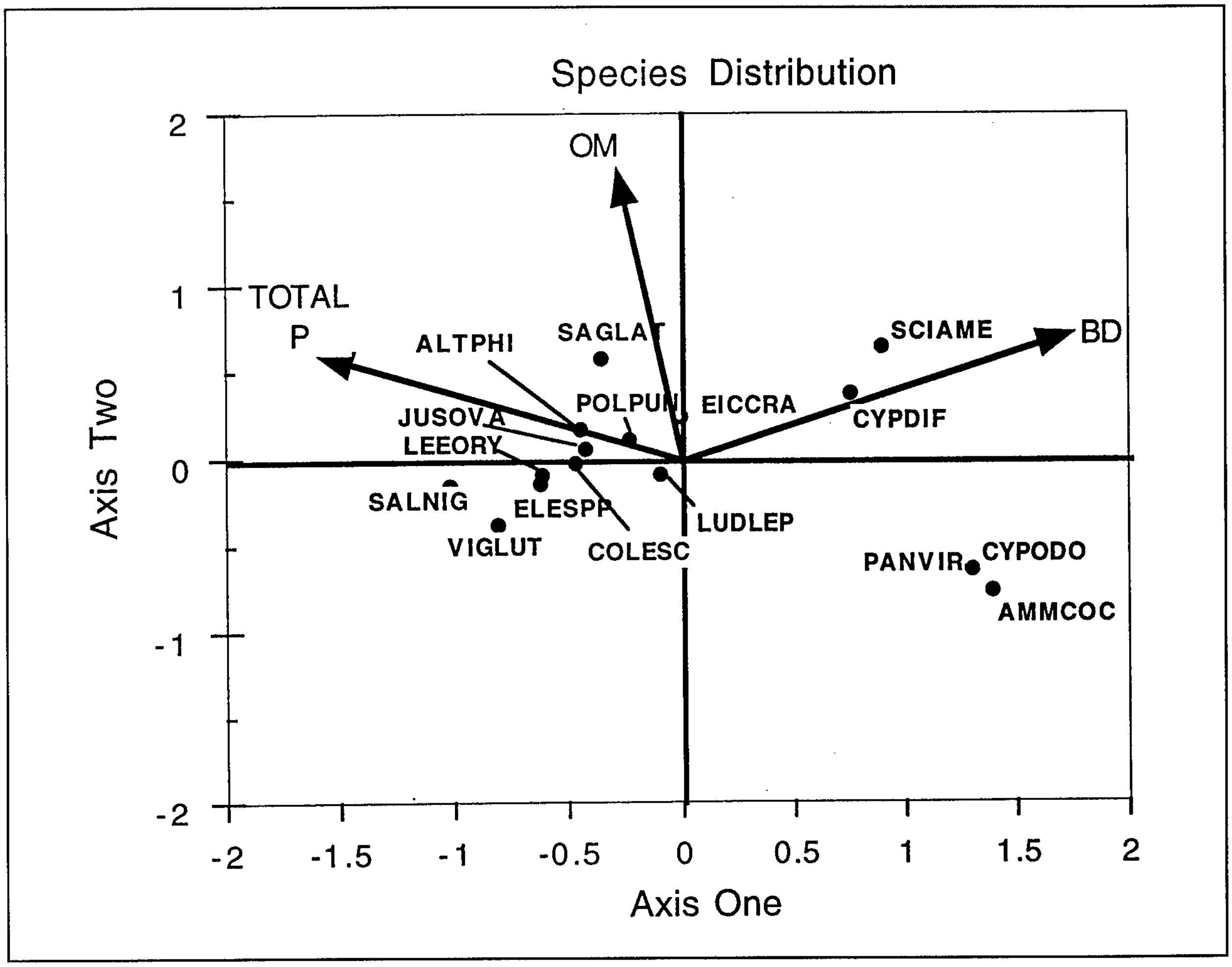

Figure 22. Canonical correspondence analysis of plant species on created and natural wetlands in the Atchafalaya Delta (excluding nonvegetated mud flats)

4 Summary and Conclusions

The obvious differences in the sediments of the young created wetland are directly attributable to the dredging process used to create the wetland. The bed-load material pumped from the river bottom initially creates a sandy sediment with low amounts of N and P. These initial differences are overcome through time with the deposition of fine-textured, nutrient-rich suspended sediments deposited on the soil surface during flooding events. A similar convergence of the vegetational characteristics between created and natural wetlands also takes place during this interval.

The results of this study indicate that it takes 5 to 10 years for created wetlands to become structurally and functionally similar to natural wetlands. These results have major implications for wetland creation science because not only is this time frame longer than the few programs designed to monitor created wetland development, it occurs under the most ideal of conditions: true wetland hydrology. Duplicating the hydrological processes necessary for long-term wetland development is the single biggest challenge to wetland creation/restoration and explains why the success rate of mitigation projects is generally low (Florida Department of Environmental Regulation 1991). Therefore, it is likely that the time required to replace lost biogeochemical wetland functions with a created wetland will be even greater in those cases where the wetland hydrology has not been adequately established.

Significant structural and functional differences between young created wetlands and older natural reference wetlands do not necessarily identify a failed attempt at wetland creation since, even under ideal conditions, young created wetlands are different from similarly aged natural wetlands. One of the reasons for choosing the Atchafalaya Delta as a study area was to eliminate differences in hydrology as a source of variation. Therefore, under the appropriate hydrological regime, early differences are reconciled after 5 to 10 years. This conclusion is further supported by the observation that the techniques used to create the young created wetland in this study are much more advanced than those used 10 and 20 years ago. These older created wetlands were built by simply piling the dredged sediment material in one place to create a mound and allow it to develop from that point. Admittedly, the primary purpose was to remove sediment and not specifically create wetlands. Yet, even these crude methods resulted in wetlands that are similar to natural wetlands in terms of structure and function. It follows, then, that

improved creation techniques should yield at least similar, if not better, results.

Finally, although the authors were not able to address the issue of inherent variability within the wetland types, the differences observed in the two old natural wetlands (Gary and Log Islands) reinforce the intuitive concept of natural variation. This variability is present within a wetland type and age class. More studies of this kind are necessary to develop a comprehensive database of the variation present in the functional attributes of natural wetlands. If natural wetlands are to be used as the goal in wetland creation/restoration and functional assessment, then the range of possible outcomes must be known. This comprehensive database will help set minimum standards or targets and provide more flexibility for measuring (and achieving) success than a single reference wetland.

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Appendix A
Seasonal Phosphorus Graphs for Atchafalaya Delta Wetlands

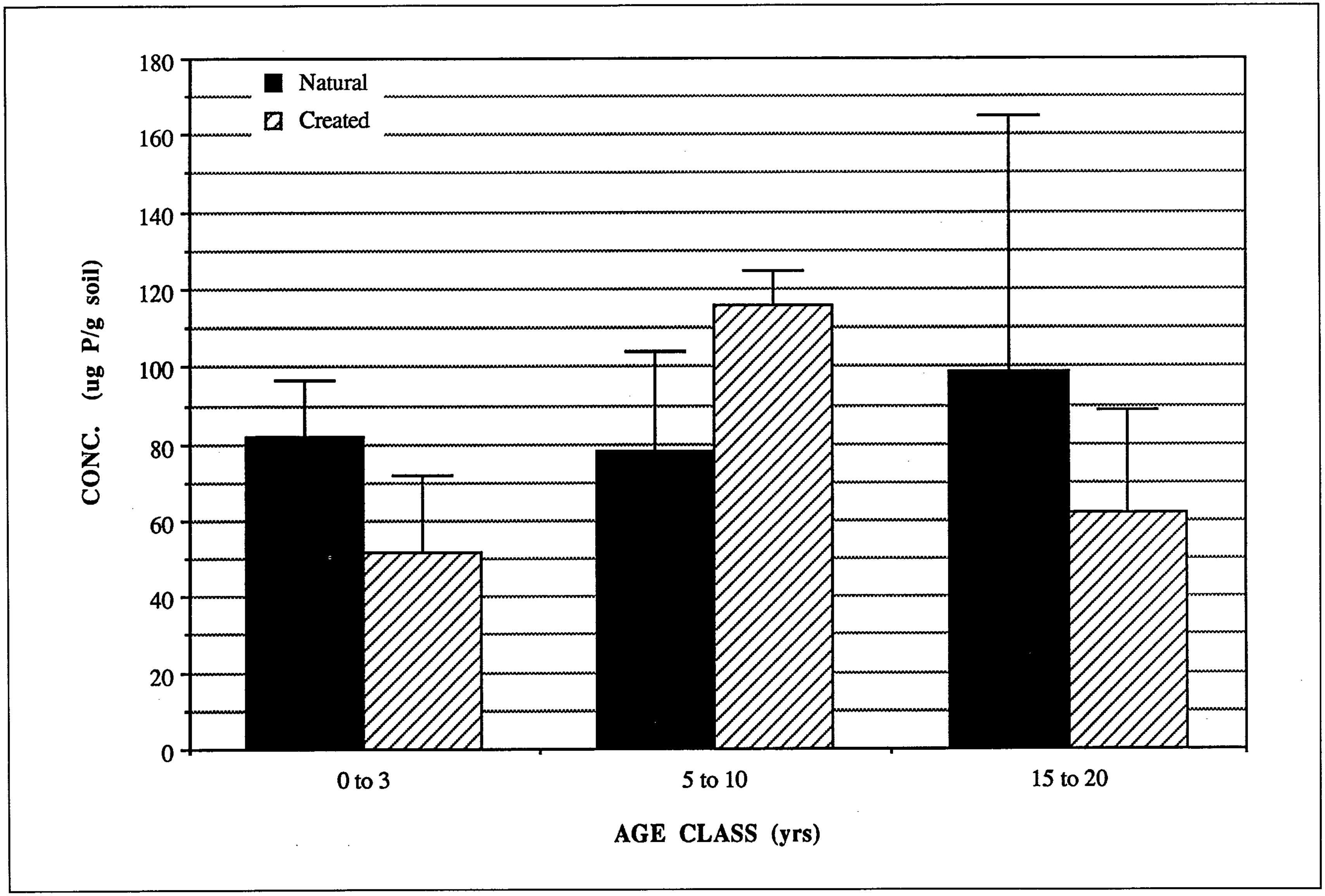

Figure A1. Comparison of mean (1 std. dev.) iron- and aluminum-bound phosphorus concentrations in similarly aged natural and created wetland soils (November 1993)

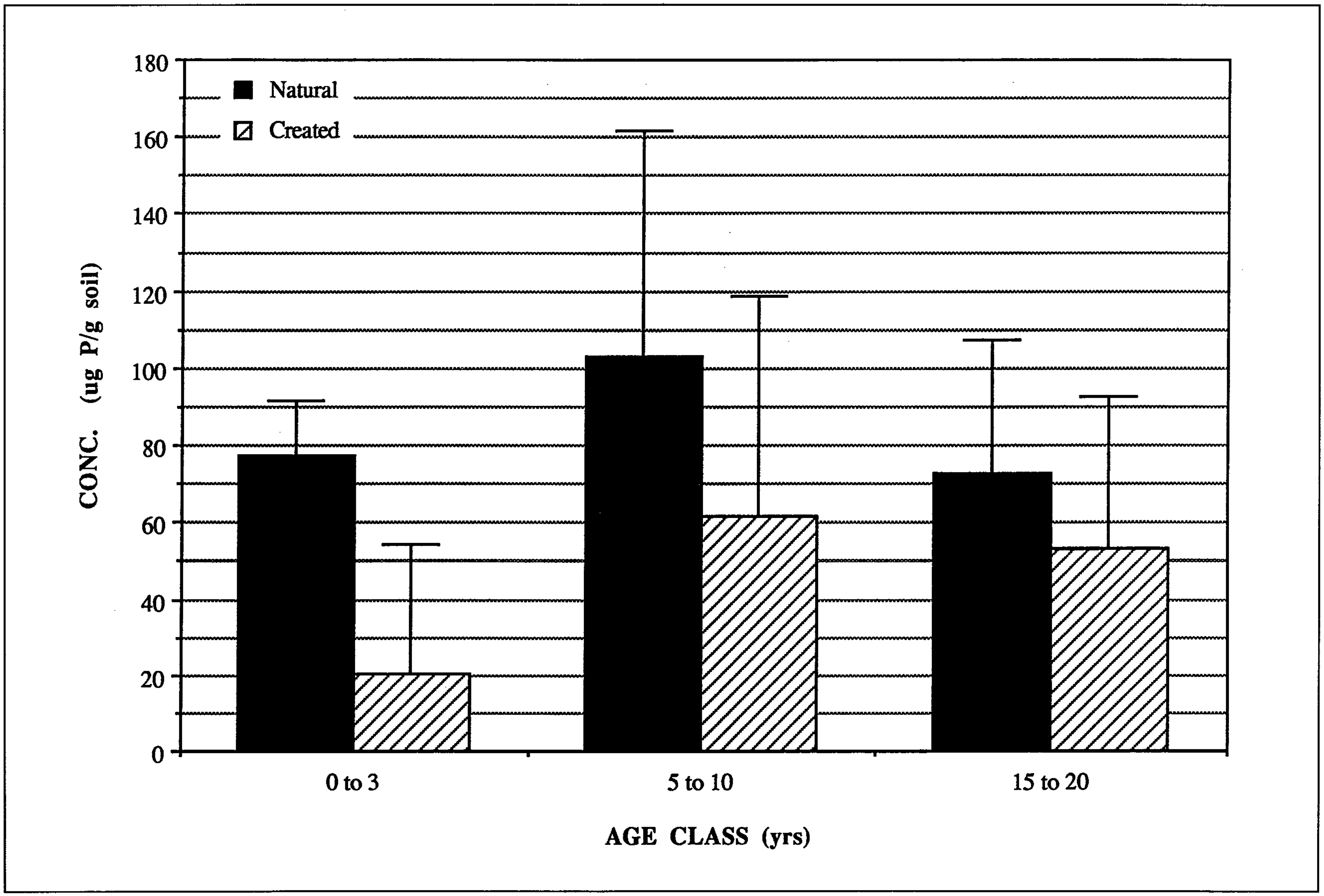

Figure A2. Comparison of mean (1 std. dev.) reductant-soluble phosphorus concentrations in similarly aged natural and created wetland soils (November 1993)

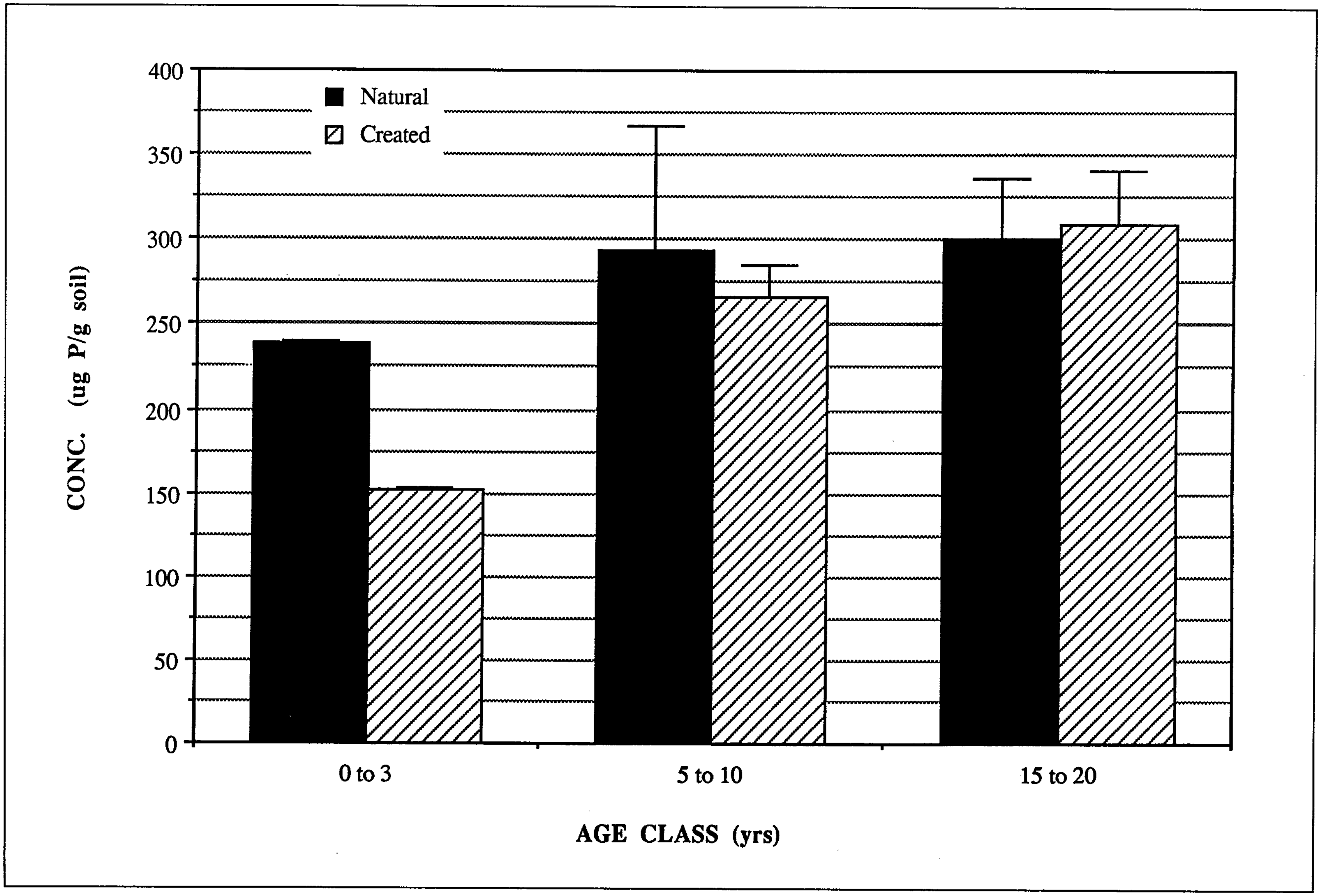

Figure A3. Comparison of mean (1 std. dev.) calcium-bound phosphorus concentrations in similarly aged natural and created wetland soils (November 1993)

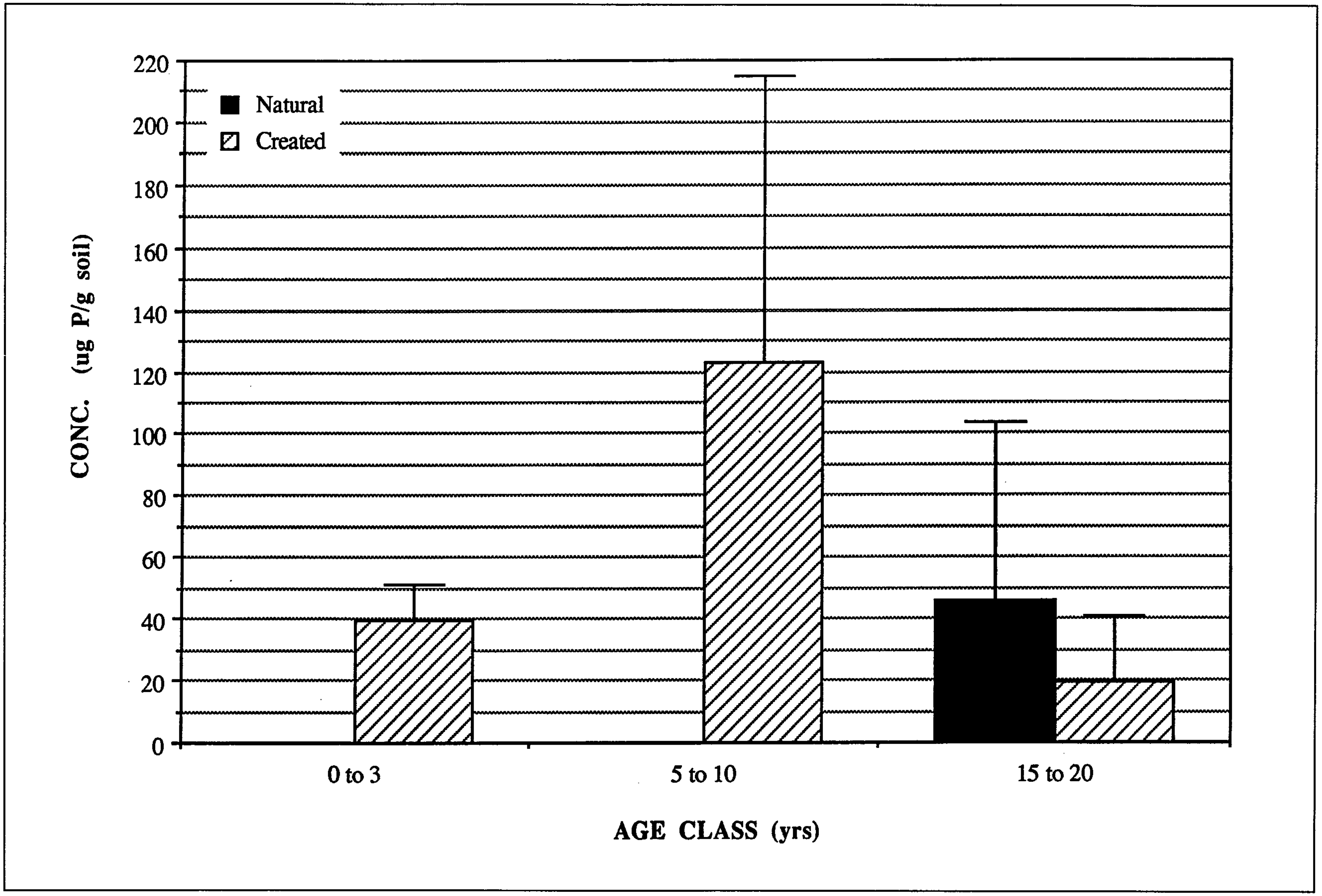

Figure A4. Comparison of mean (1 std. dev.) organic phosphorus concentrations in similarly aged natural and created wetland soils (November 1993)

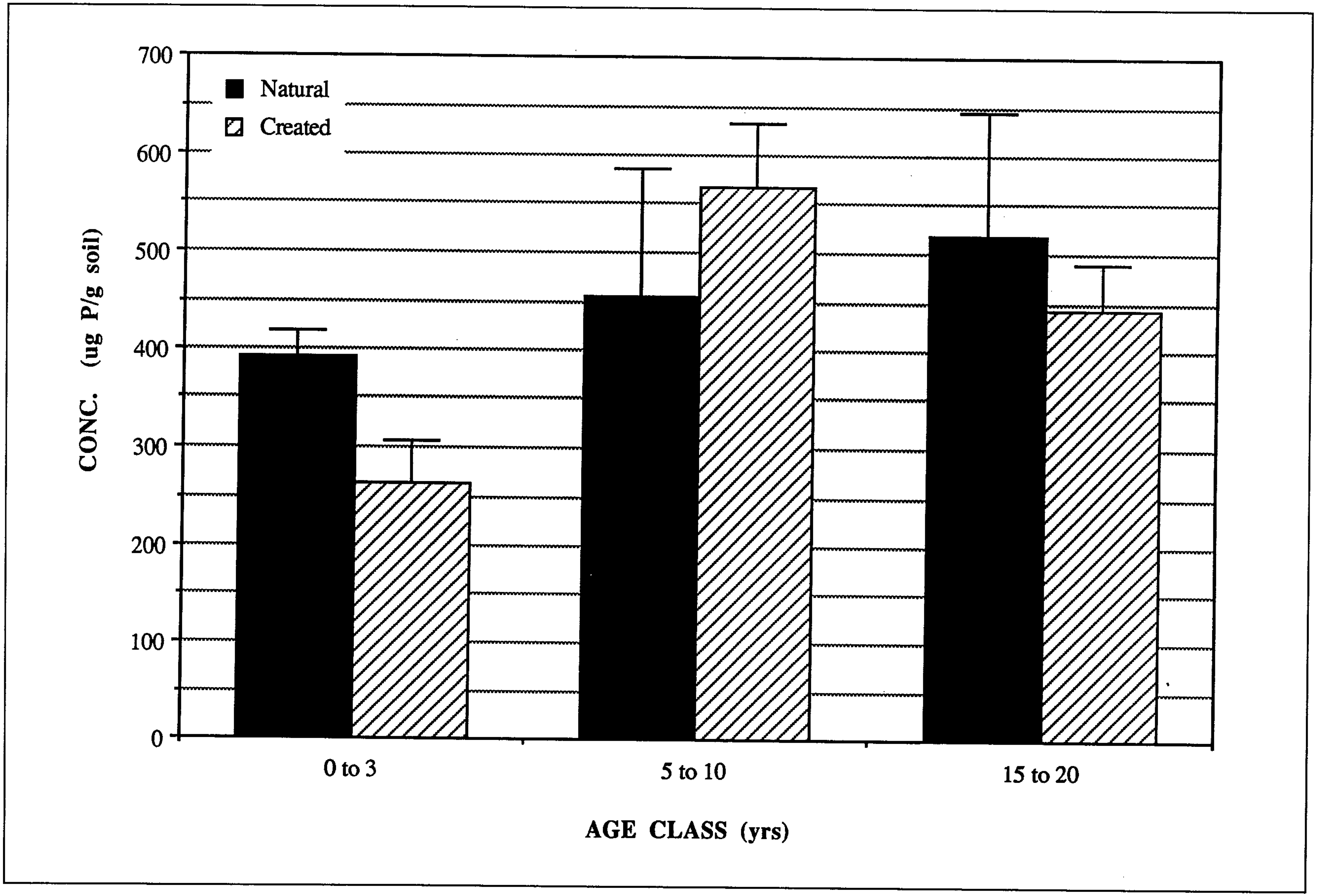

Figure A5. Comparison of mean (1 std. dev.) total soil phosphorus concentrations in similarly aged natural and created wetland soils (November 1993)

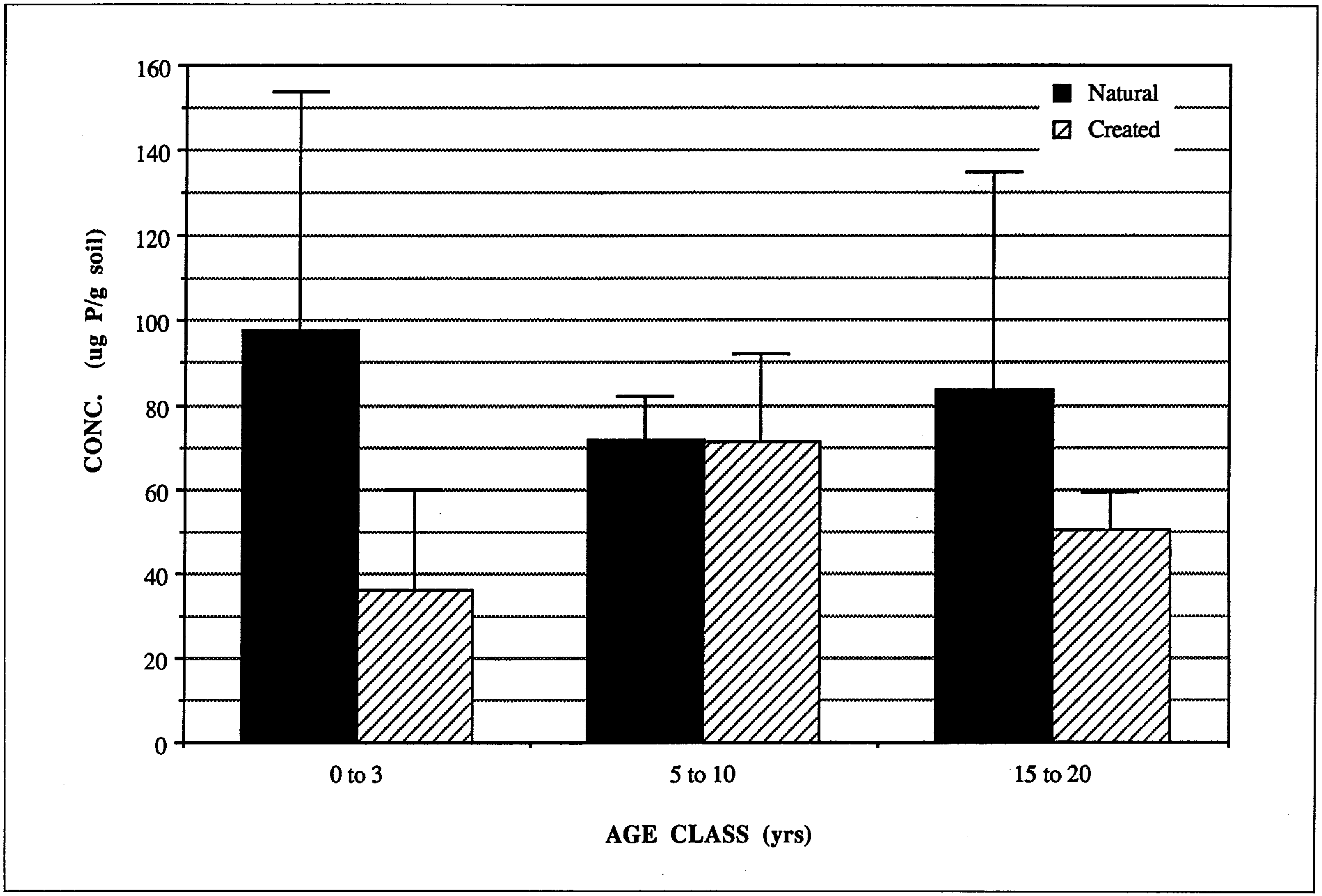

Figure A6. Comparison of mean (1 std. dev.) iron- and aluminum-bound phosphorus concentrations in similarly aged natural and created wetland soils (December 1993)

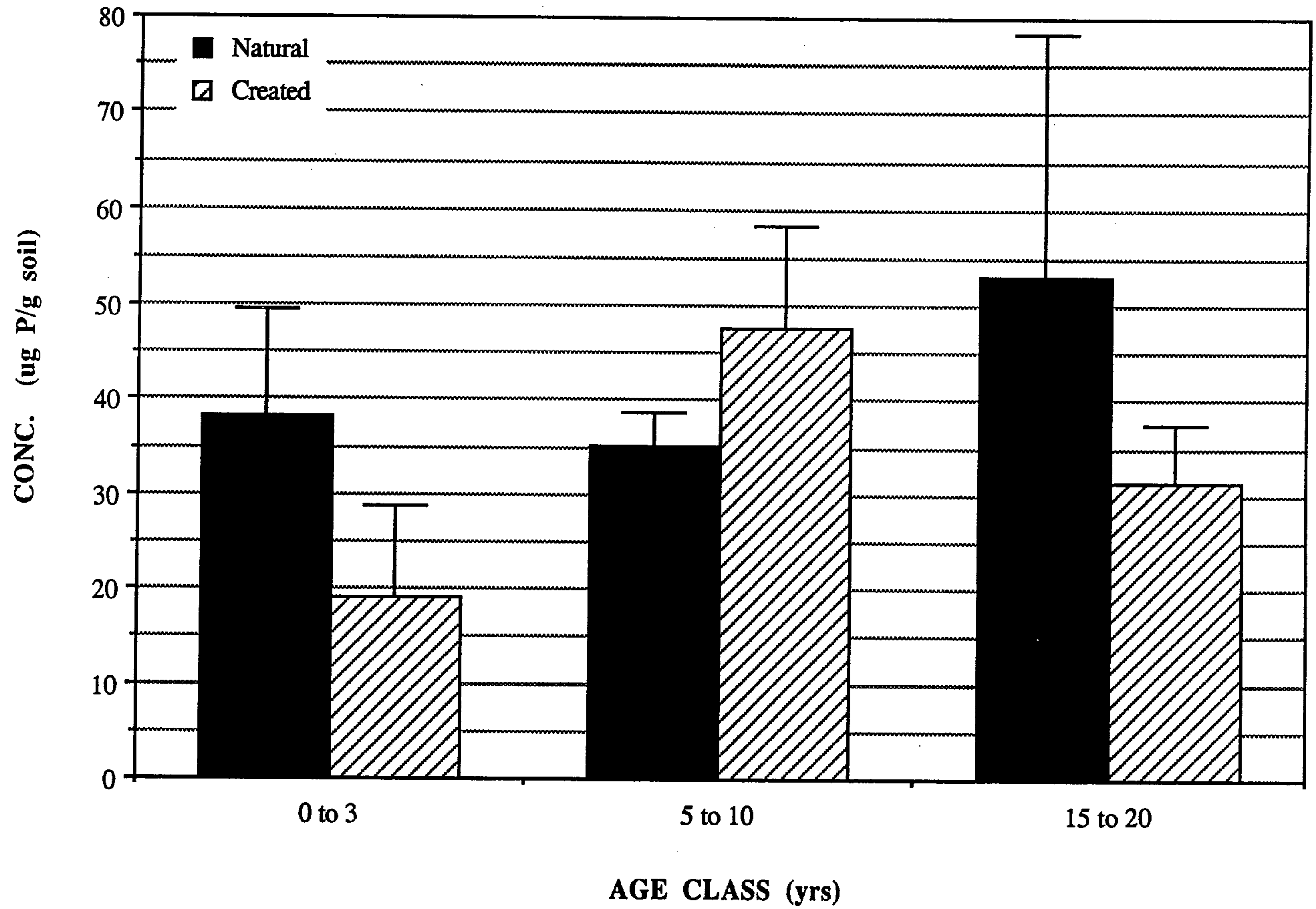

Figure A7. Comparison of mean (1 std. dev.) reductant-soluble phosphorus concentrations in similarly aged natural and created wetland soils (December 1993)

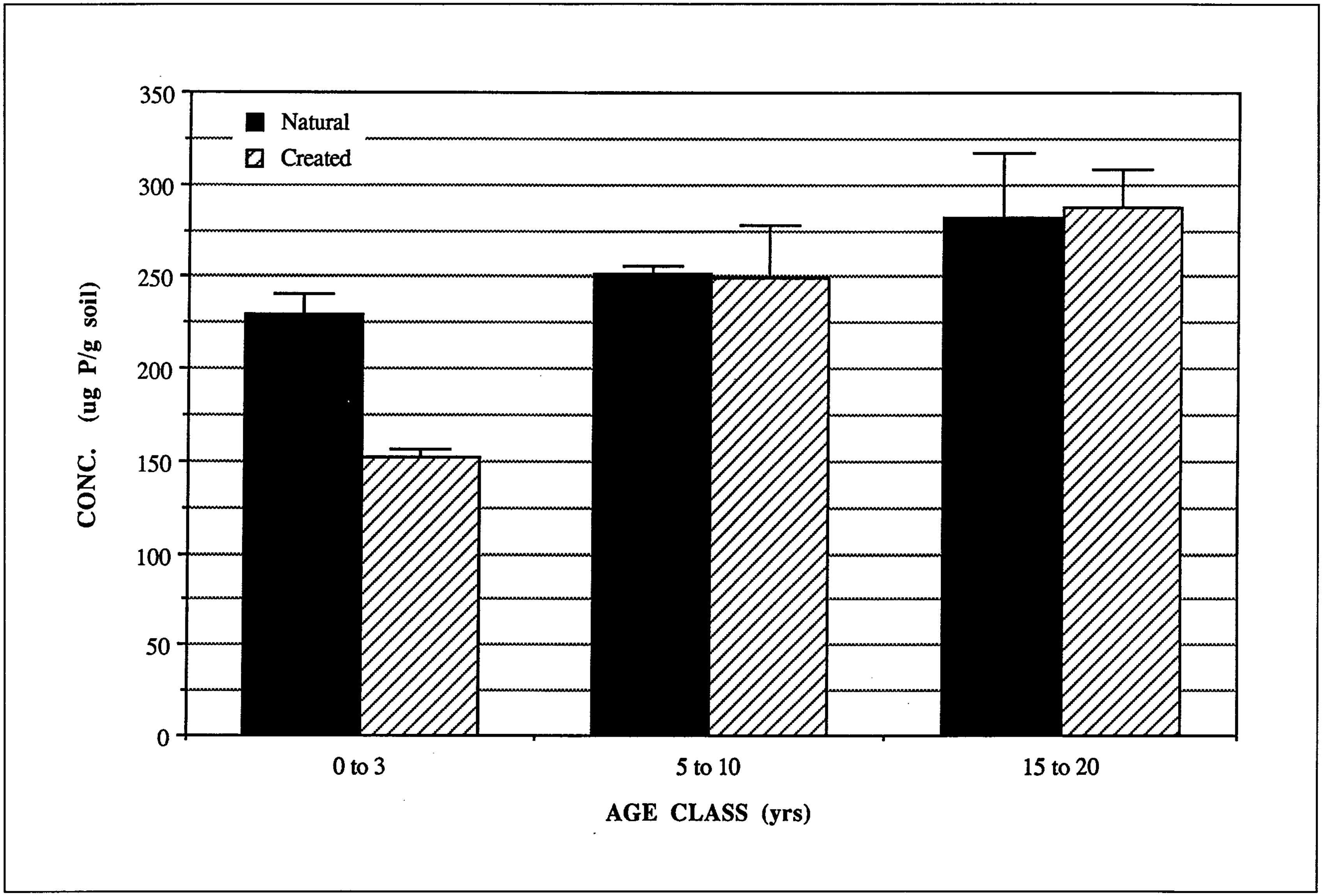

Figure A8. Comparison of mean (1 std. dev.) calcium-bound phosphorus concentrations in similarly aged natural and created wetland soils (December 1993)

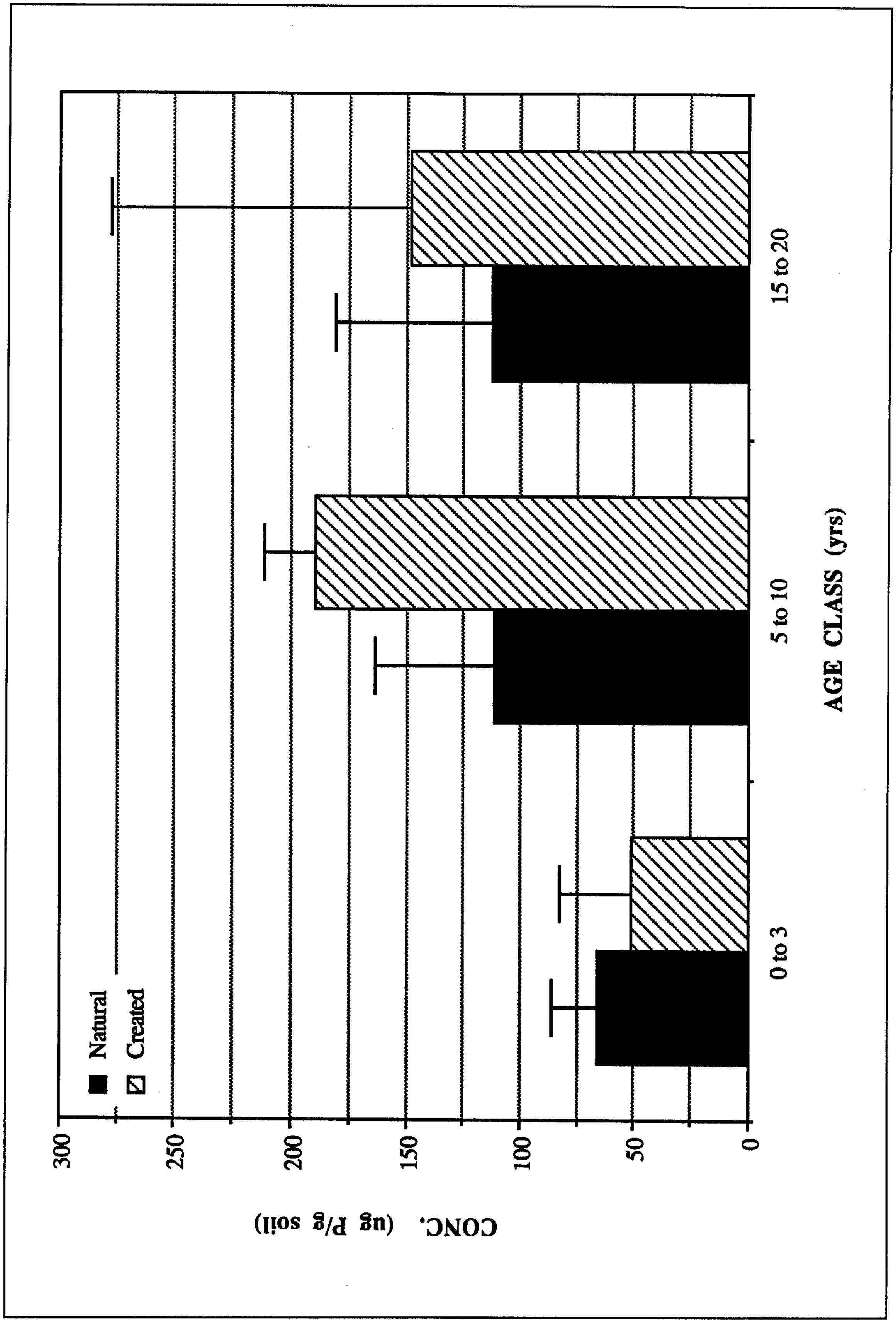

Figure A9. Comparison of mean (1 std. dev.) organic phosphorus concentrations in similarly aged natural and created wetland soils (December 1993)

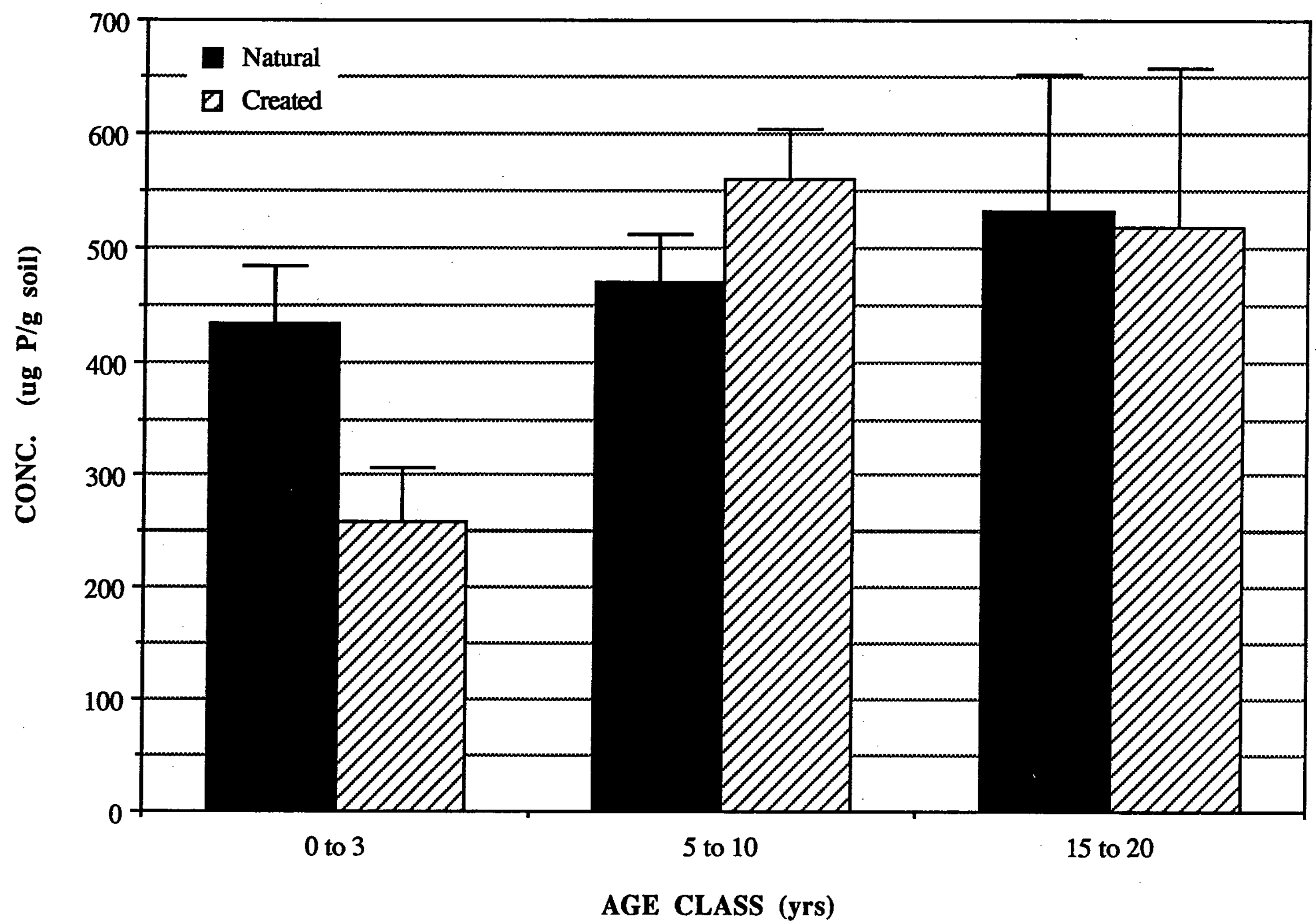

Figure A10. Comparison of mean (1 std. dev.) total soil phosphorus concentrations in similarly aged natural and created wetland soils (December 1993)

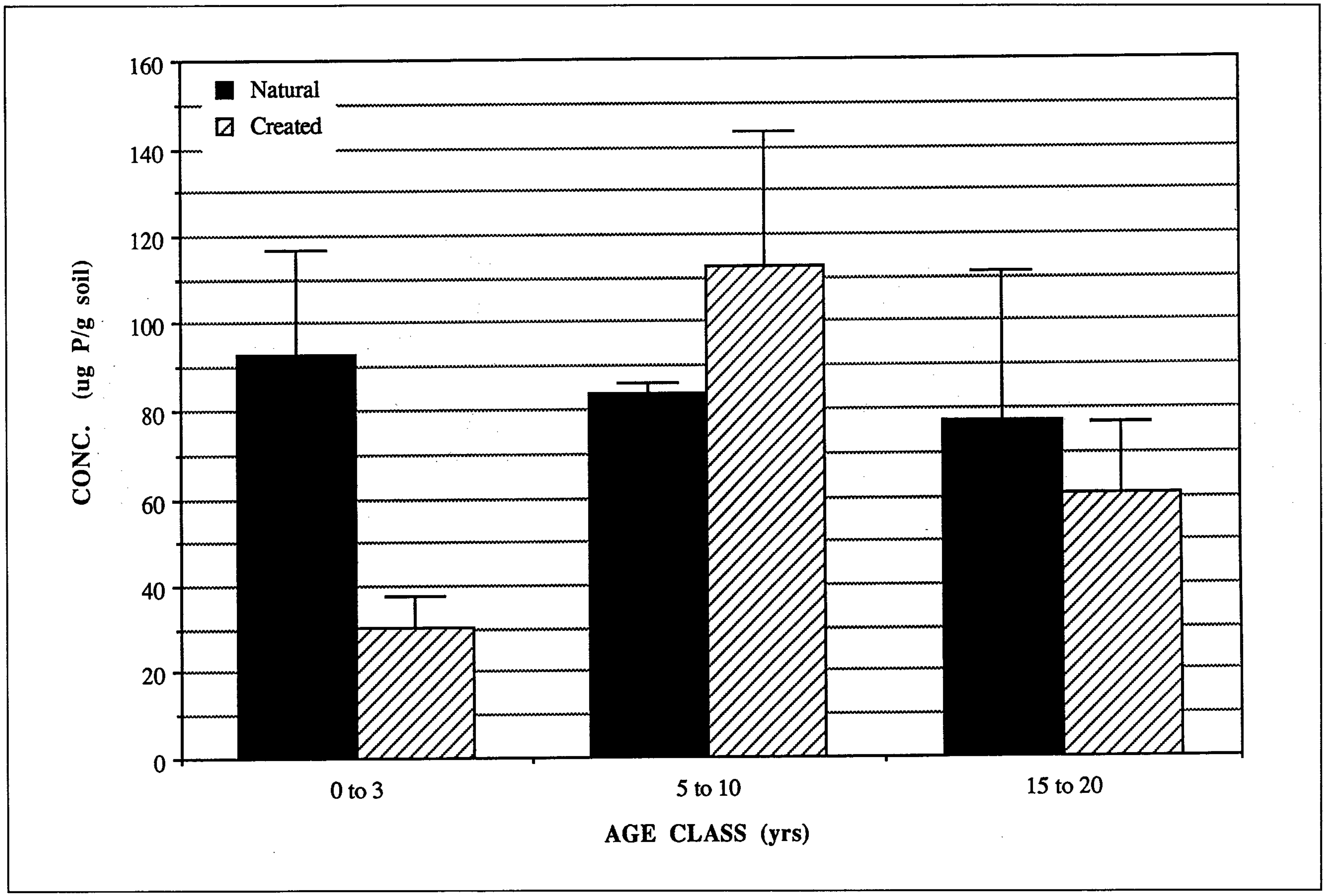

Figure A11. Comparison of mean (1 std. dev.) iron- and aluminum-bound phosphorus concentrations in similarly aged natural and created wetland soils (January 1994)

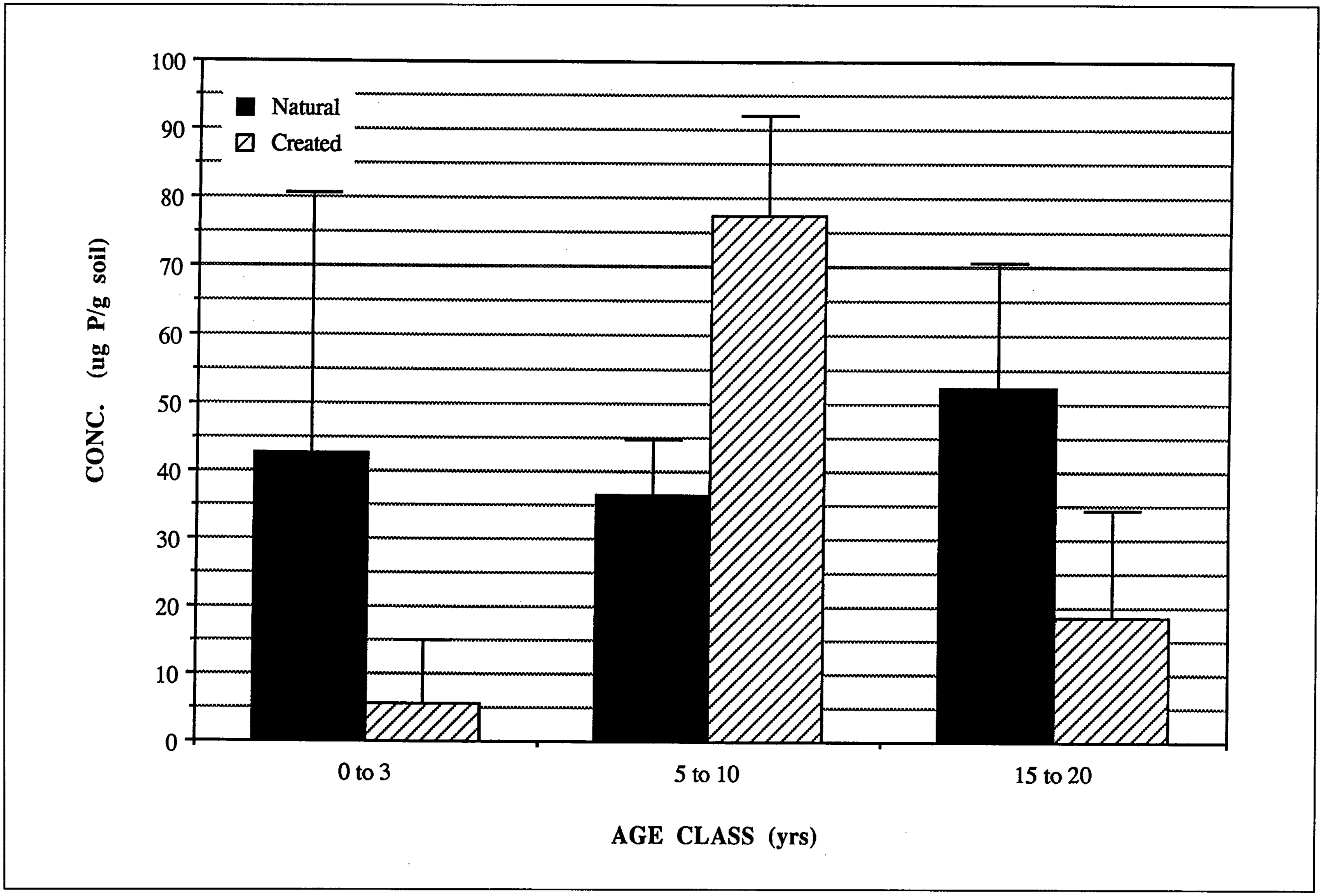

Figure A12. Comparison of mean (1 std. dev.) reductant-soluble phosphorus concentrations in similarly aged natural and created wetland soils (January 1994)

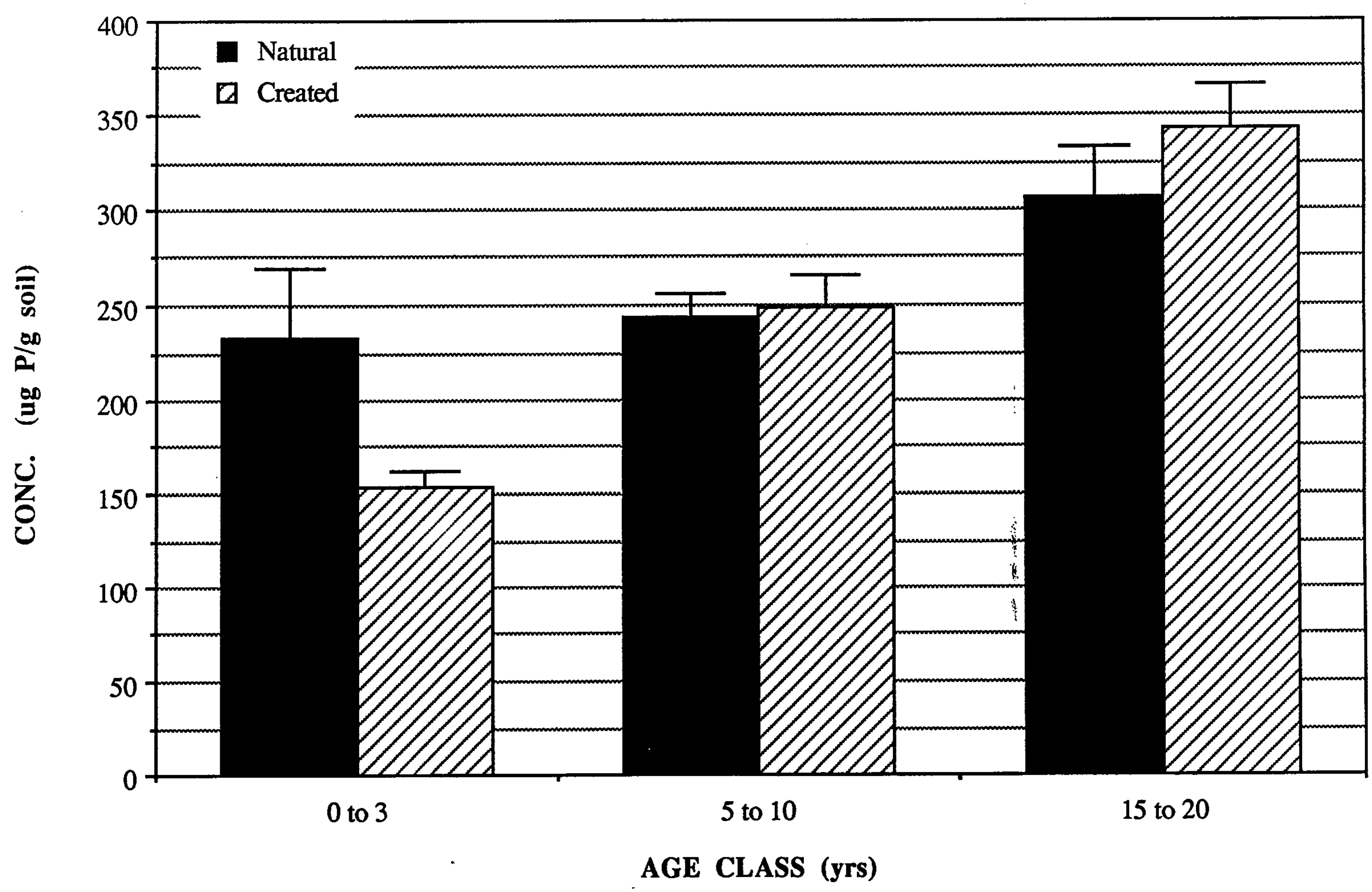

Figure A13. Comparison of mean (1 std. dev.) calcium-bound phosphorus concentrations in similarly aged natural and created wetland soils (January 1994)

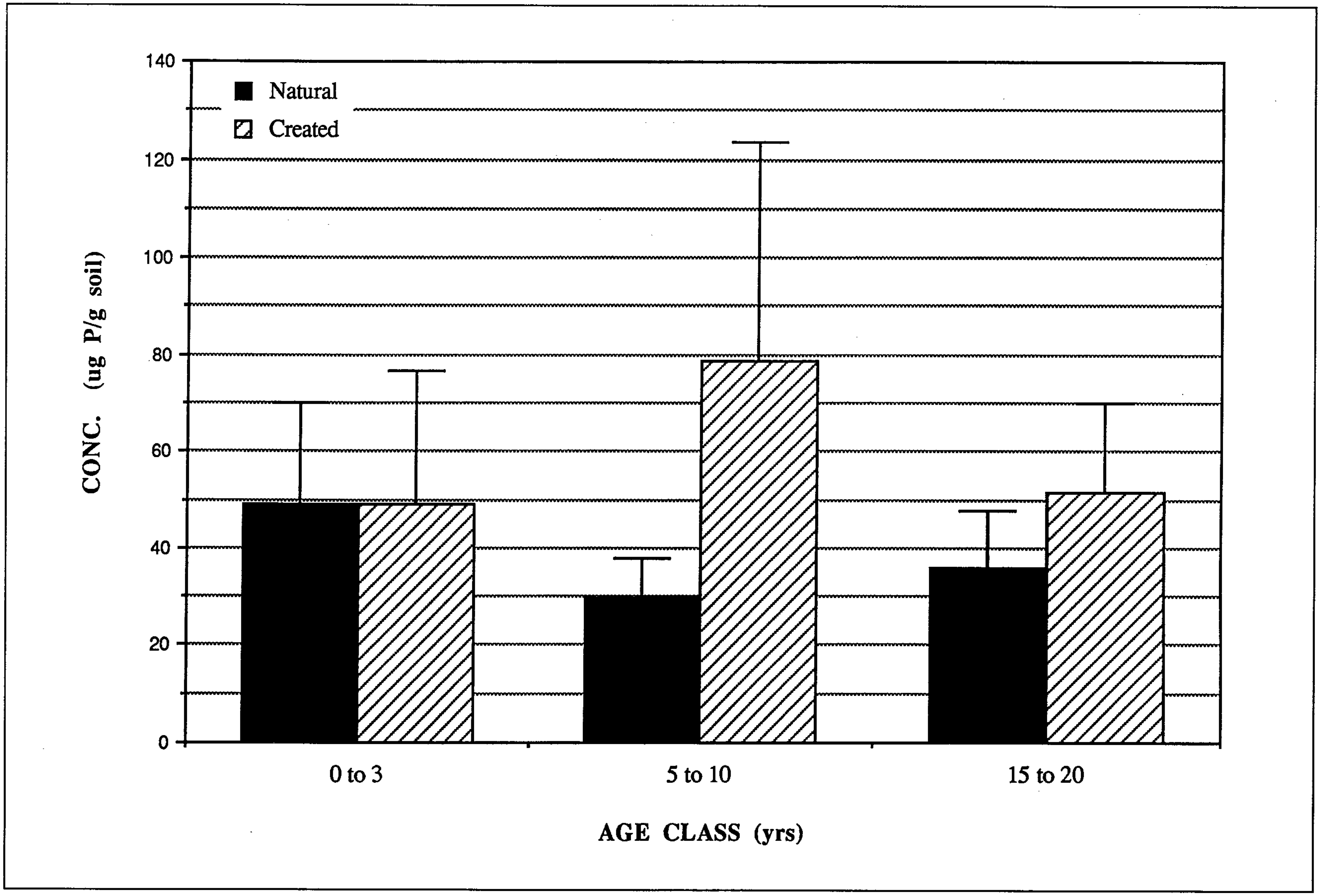

Figure A14. Comparison of mean (1 std. dev.) organic phosphorus concentrations in similarly aged natural and created wetland soils (January 1994)

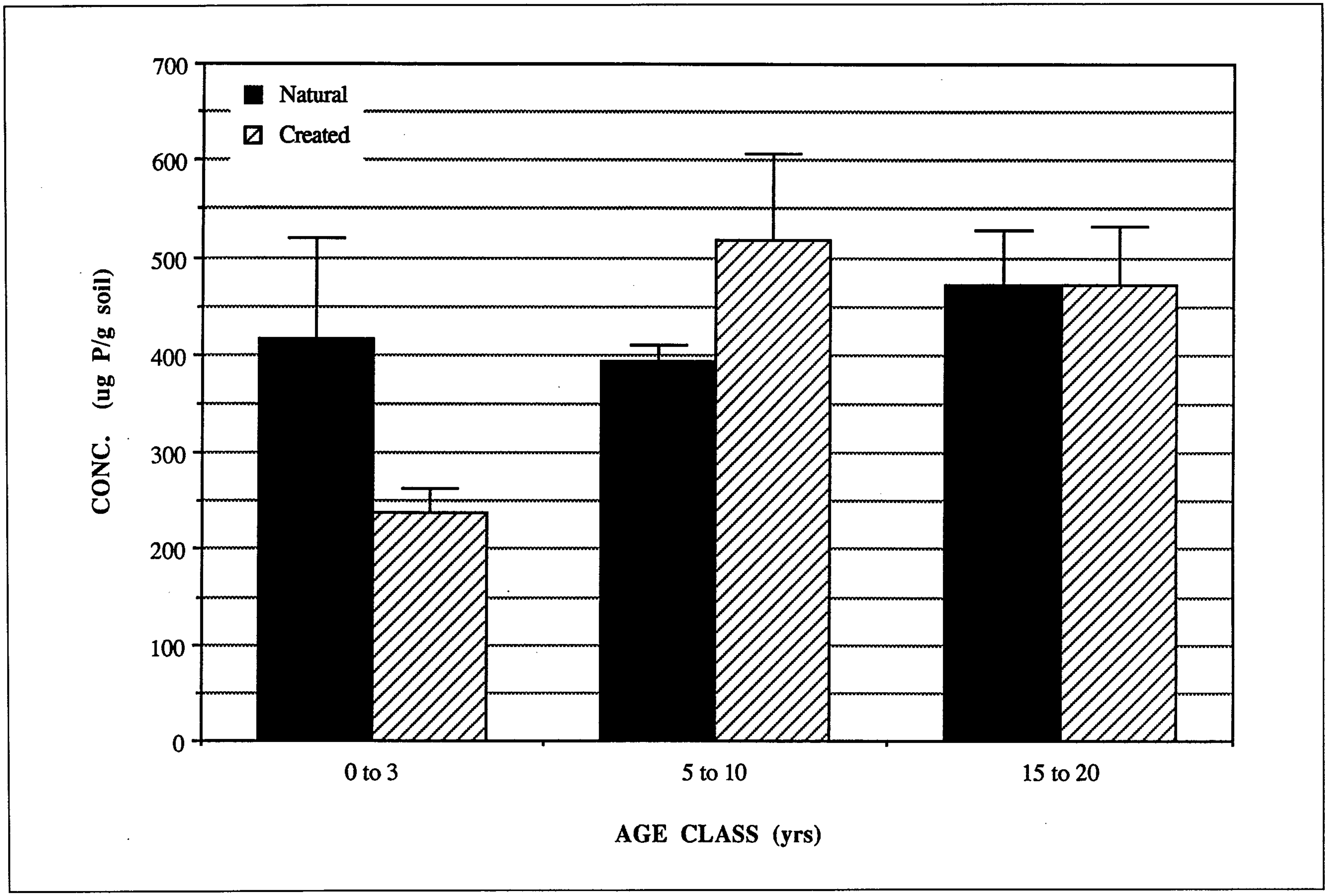

Figure A15. Comparison of mean (1 std. dev.) total soil phosphorus concentrations in similarly aged natural and created wetland soils (January 1994)

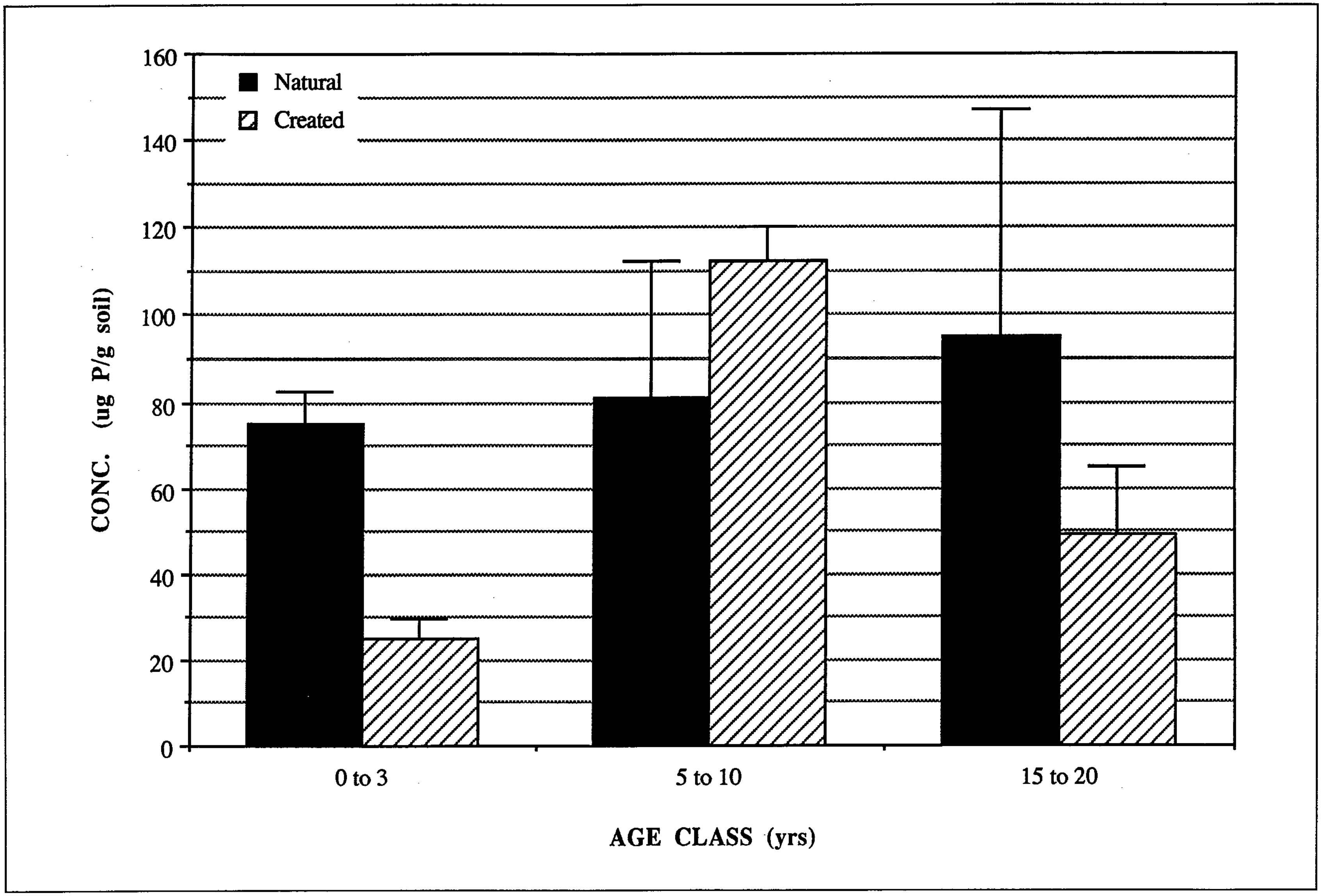

Figure A16. Comparison of mean (1 std. dev.) iron- and aluminum-bound phosphorus concentrations in similarly aged natural and created wetland soils (May 1994)

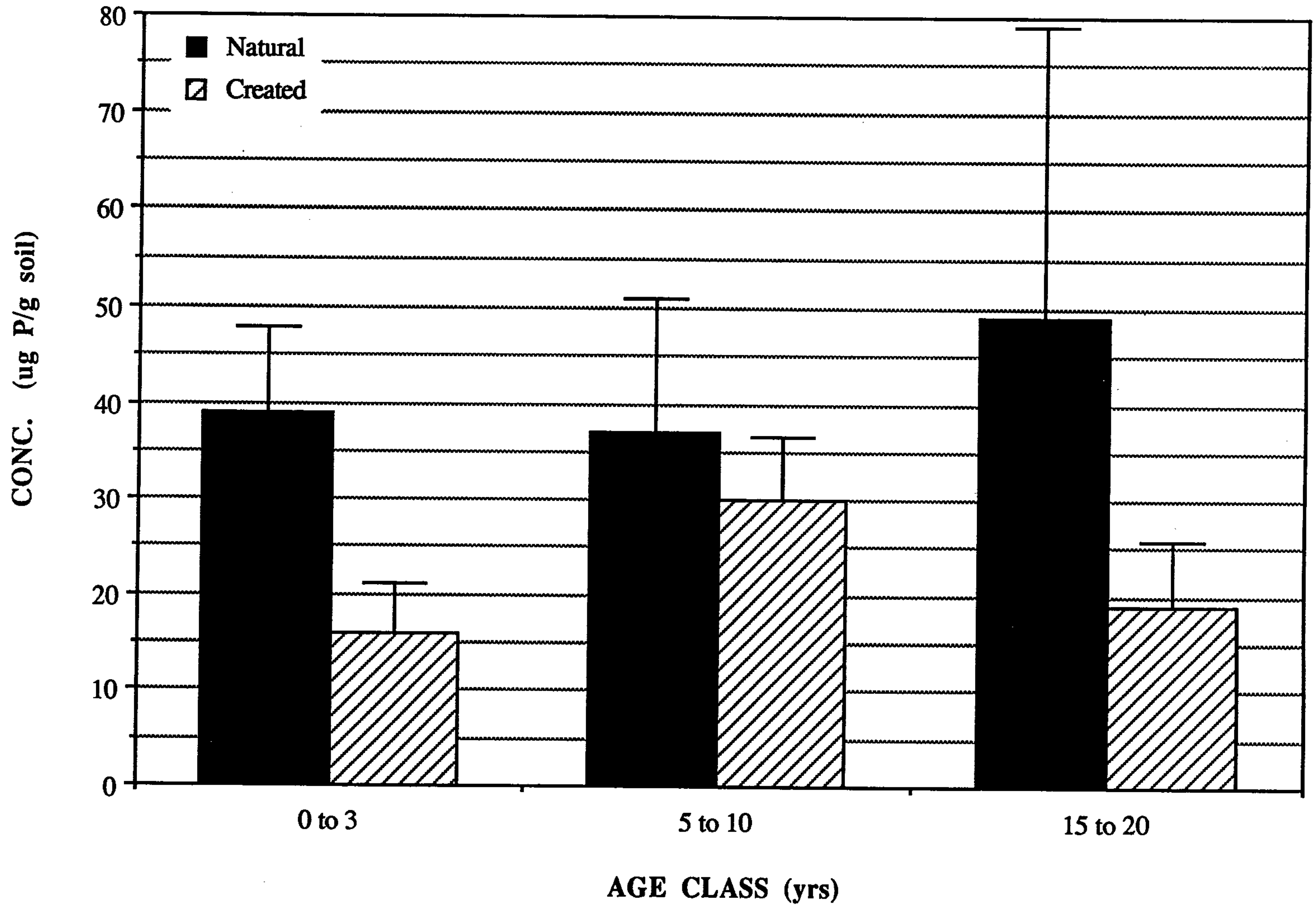

Figure A17. Comparison of mean (1 std. dev.) reductant-soluble phosphorus concentrations in similarly aged natural and created wetland soils (May 1994)

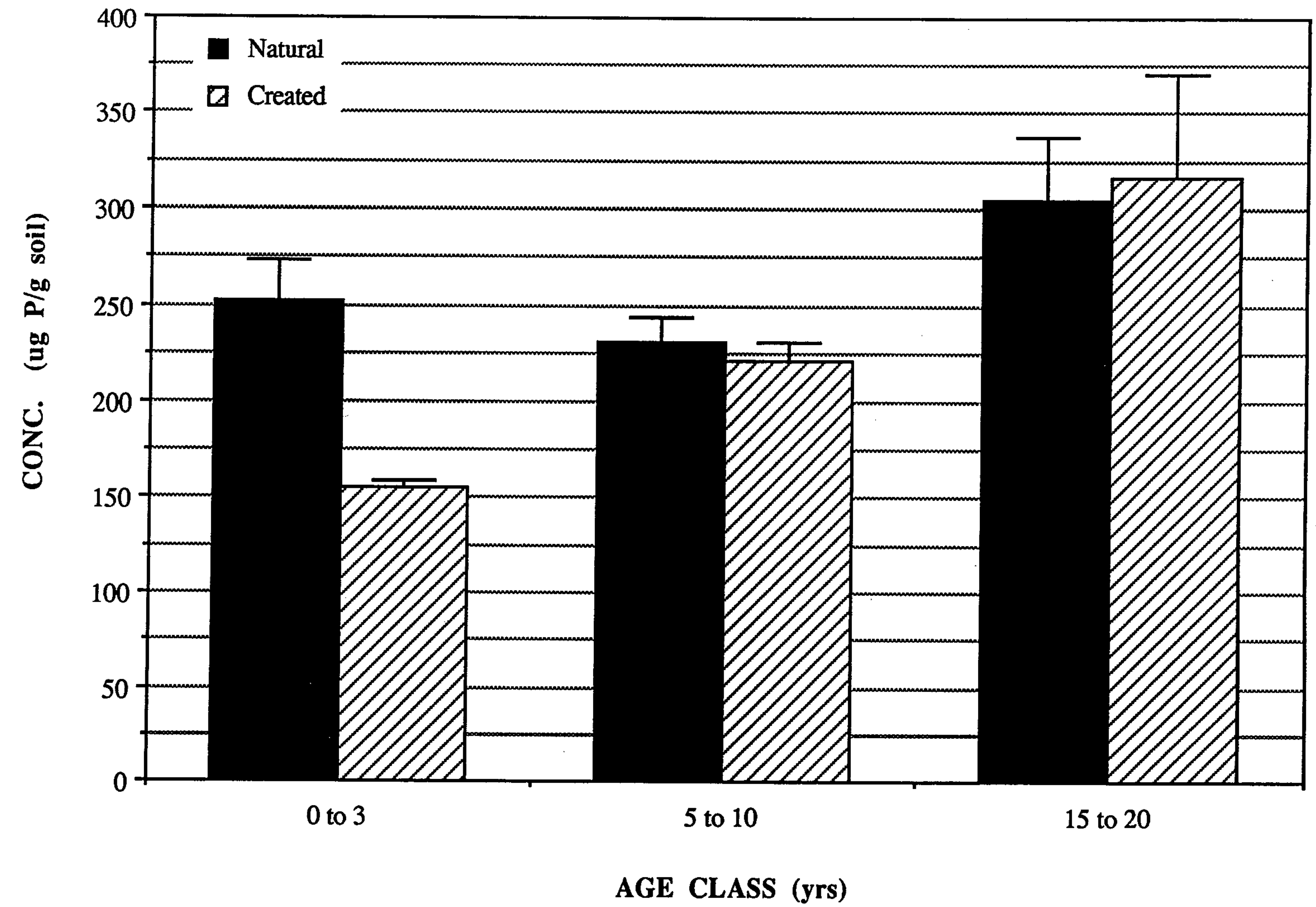

Figure A18. Comparison of mean (1 std. dev.) calcium-bound phosphorus concentrations in similarly aged natural and created wetland soils (May 1994)

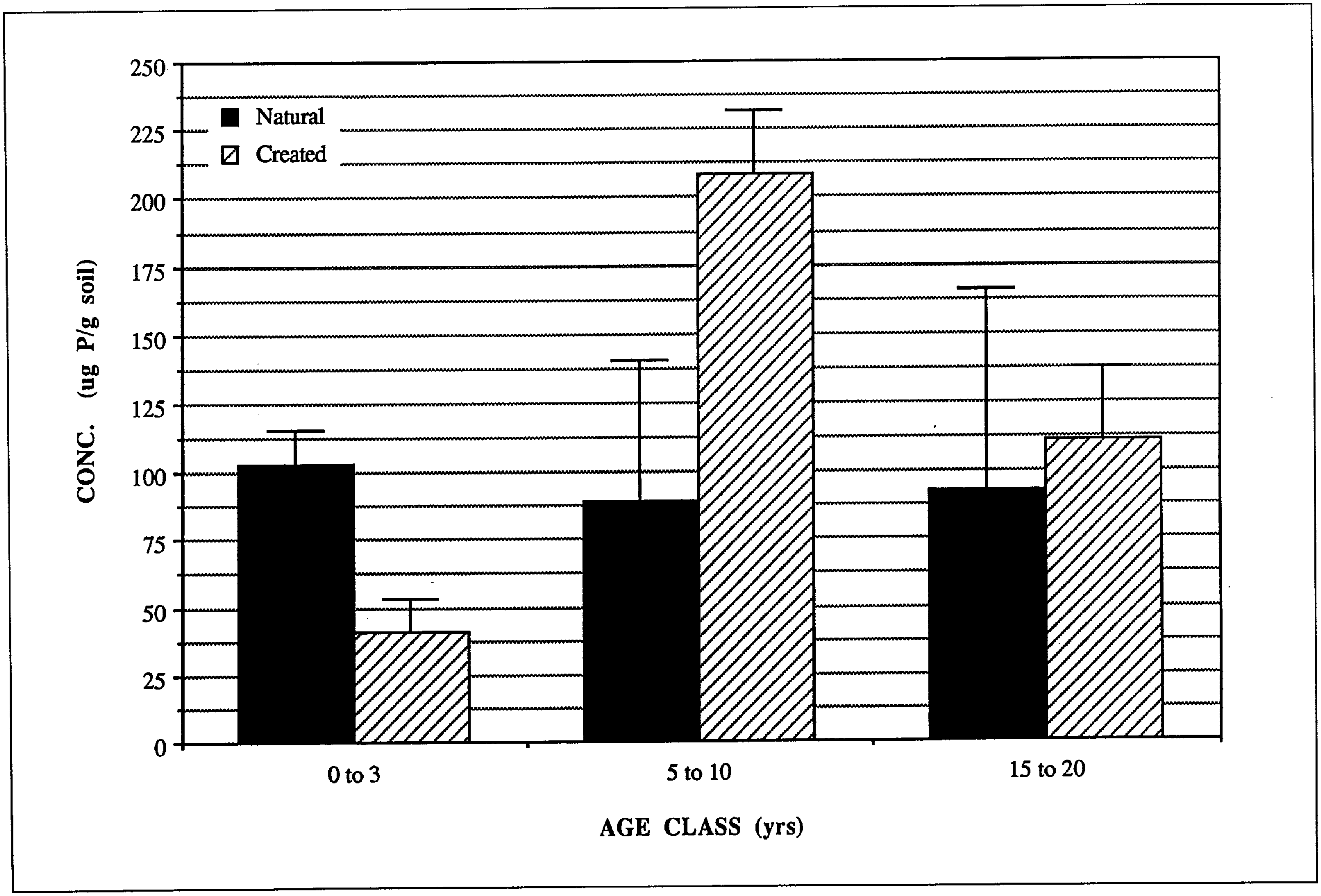

Figure A19. Comparison of mean (1 std. dev.) organic phosphorus concentrations in similarly aged natural and created wetland soils (May 1994)

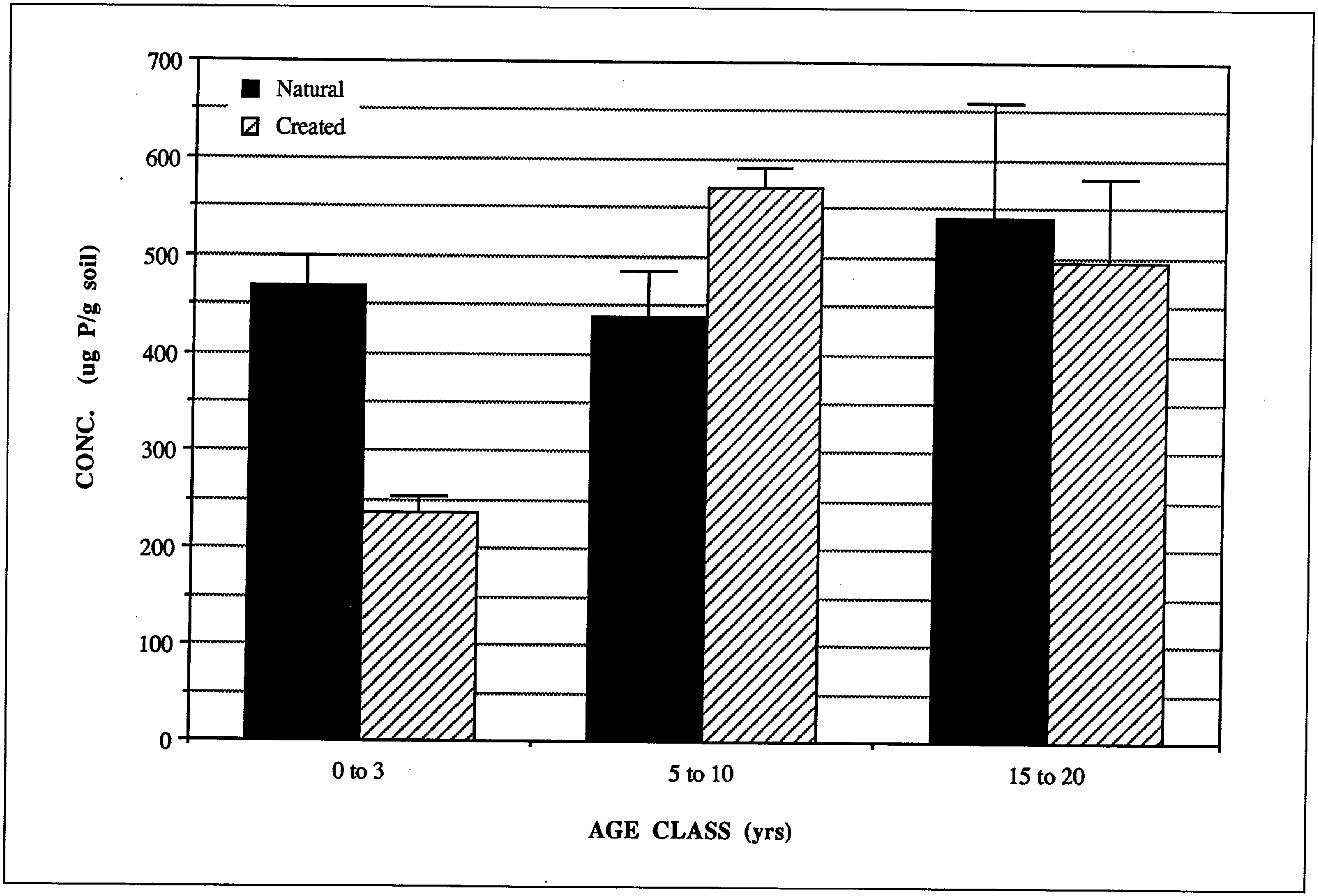

Figure A20. Comparison of mean (1 std. dev.) total soil phosphorus concentrations in similarly aged natural and created wetland soils (May 1994)

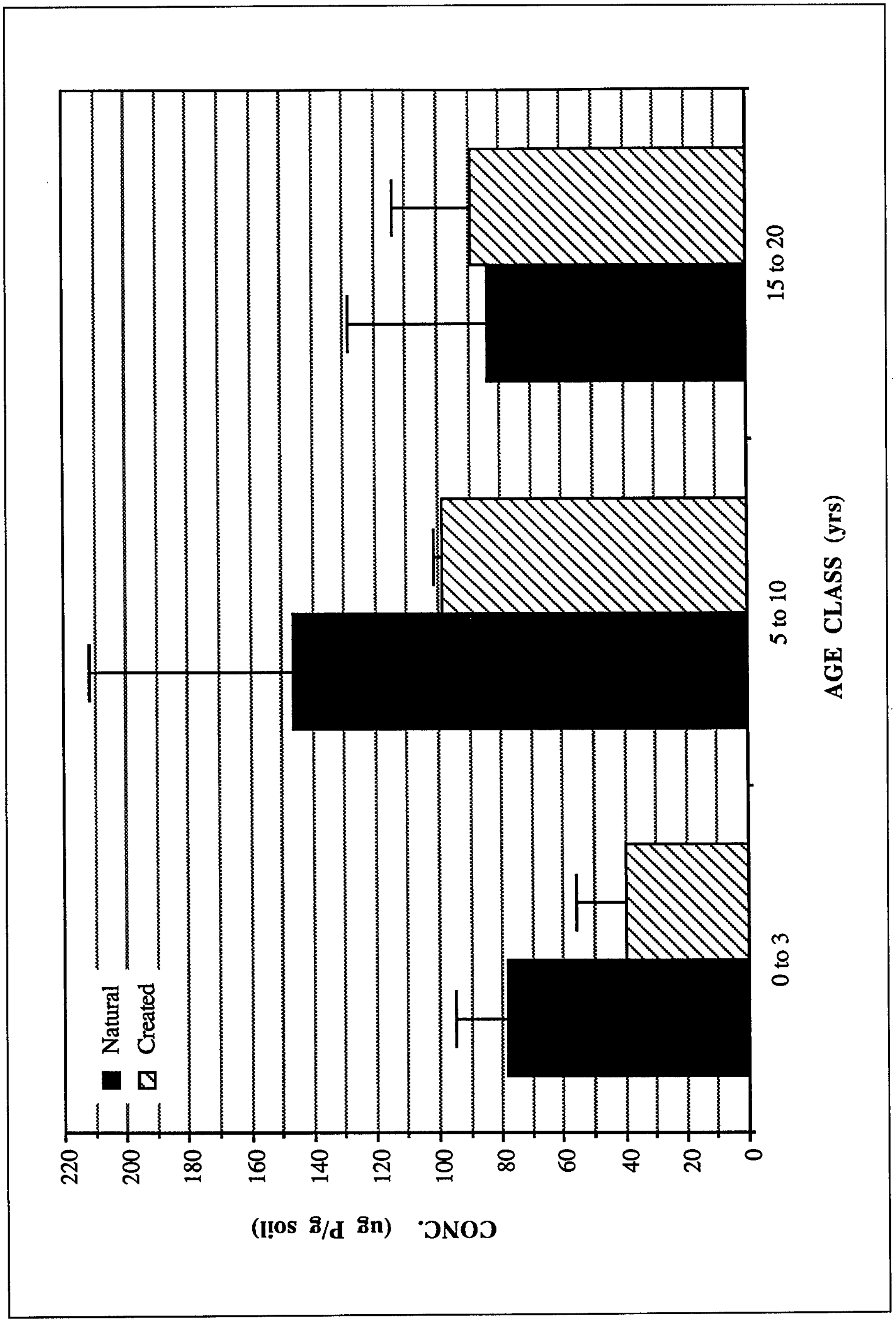

Figure A21. Comparison of mean (1 std. dev.) iron- and aluminum-bound phosphorus concentrations in similarly aged natural and created wetland soils (July 1994)

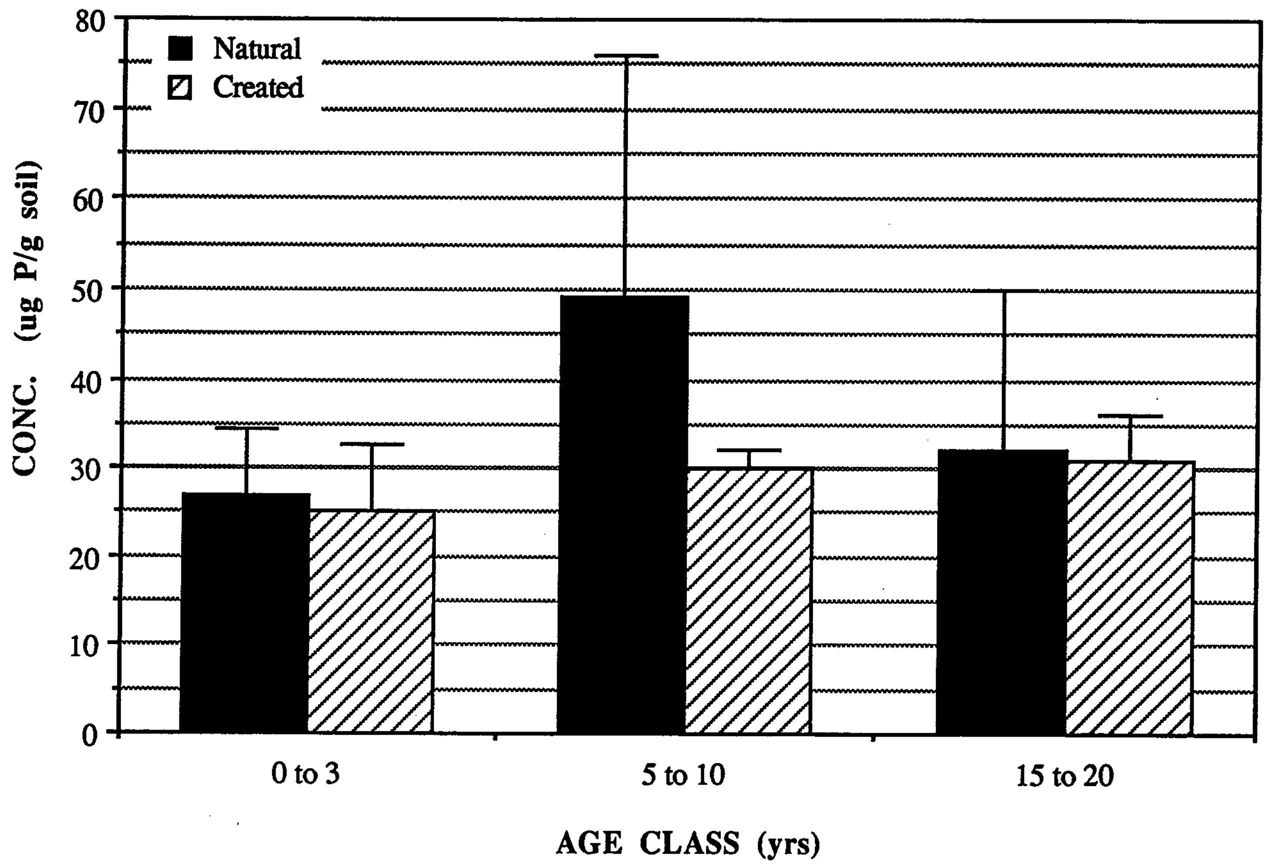

Figure A22. Comparison of mean (1 std. dev.) reductant-soluble phosphorus concentrations in similarly aged natural and created wetland soils (July 1994)

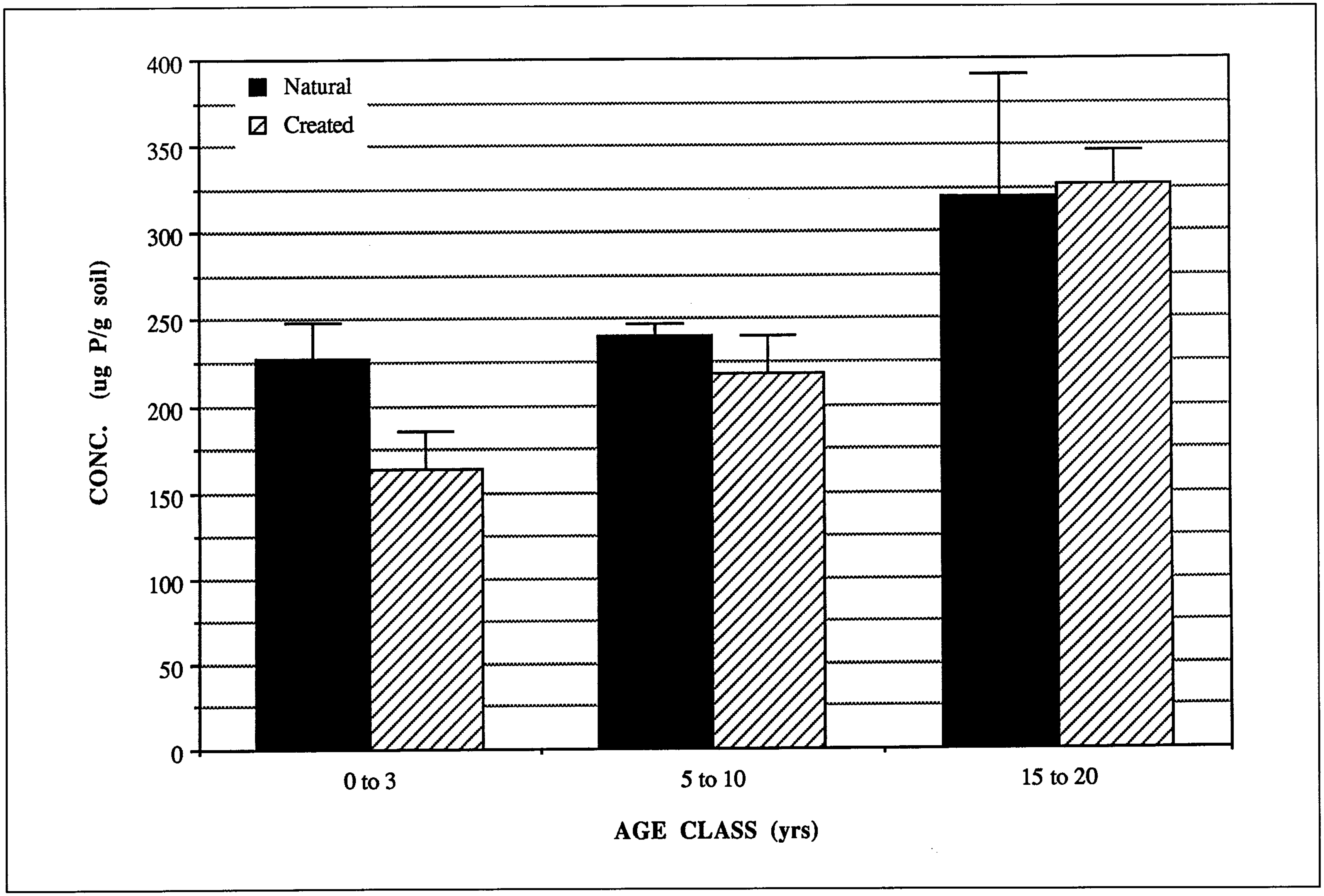

Figure A23. Comparison of mean (1 std. dev.) calcium-bound phosphorus concentrations in similarly aged natural and created wetland soils (July 1994)

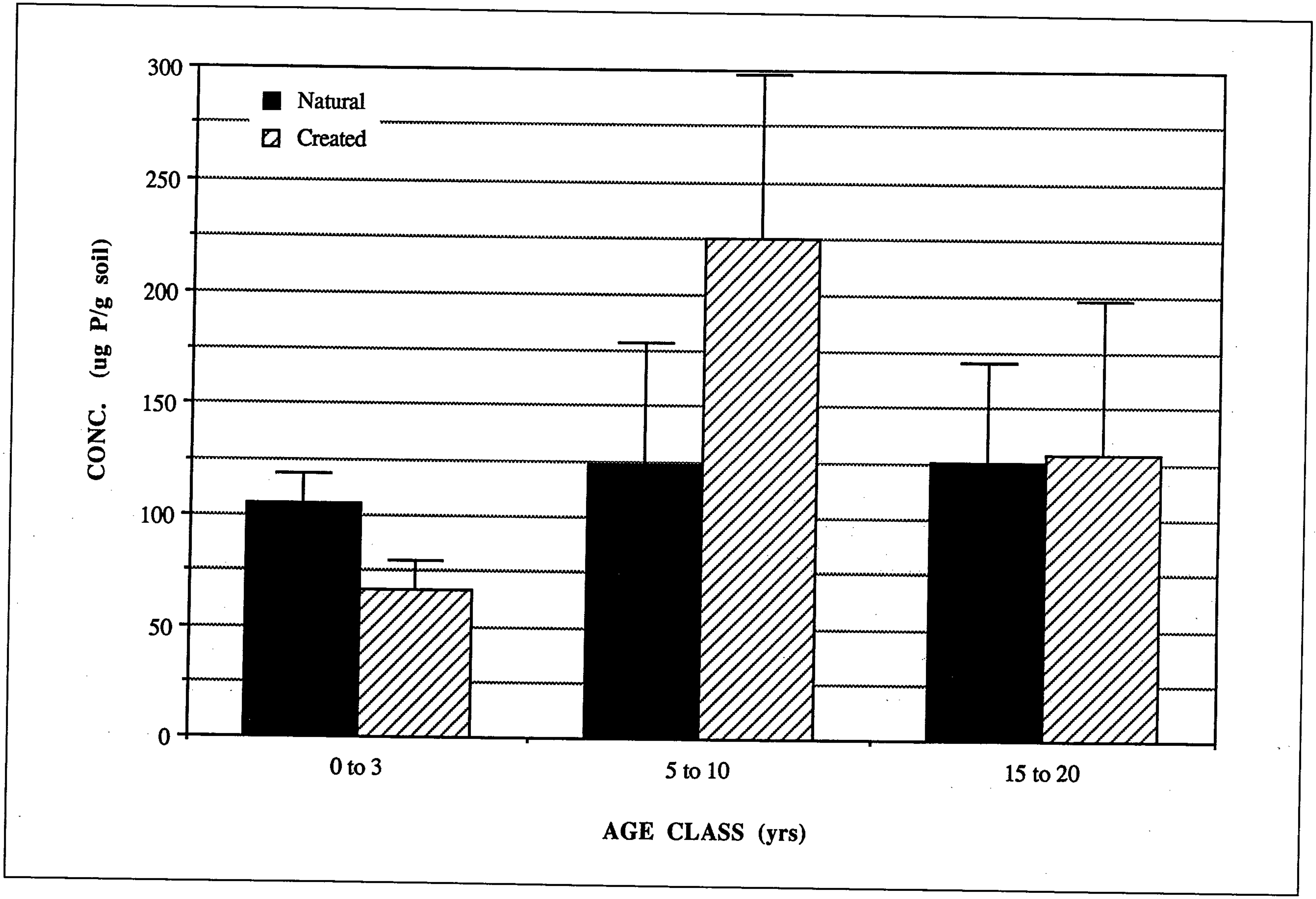

Figure A24. Comparison of mean (1 std. dev.) organic phosphorus concentrations in similarly aged natural and created wetland soils (July 1994)

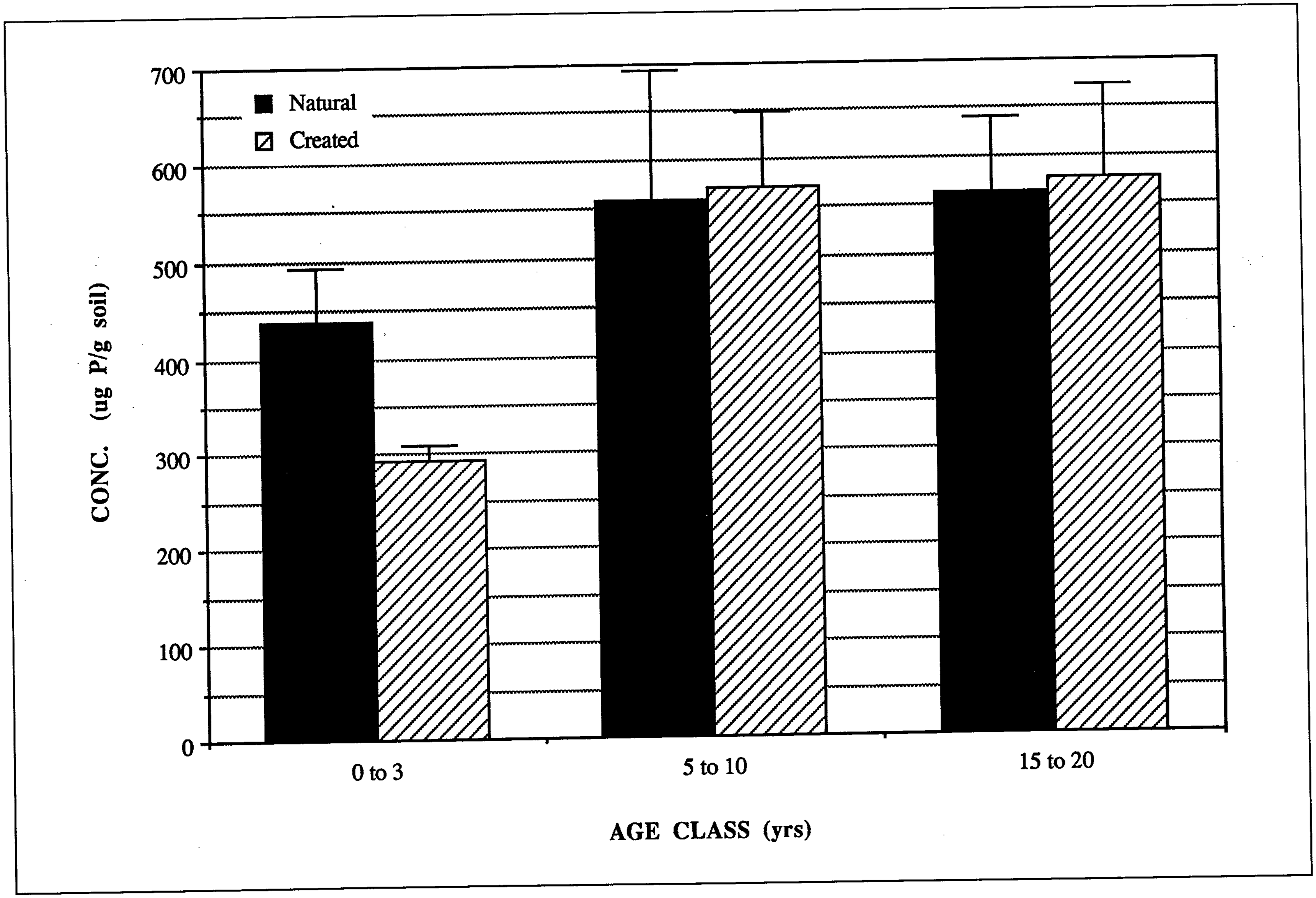

Figure A25. Comparison of mean (1 std. dev.) total soil phosphorus concentrations in similarly aged natural and created wetland soils (July 1994)

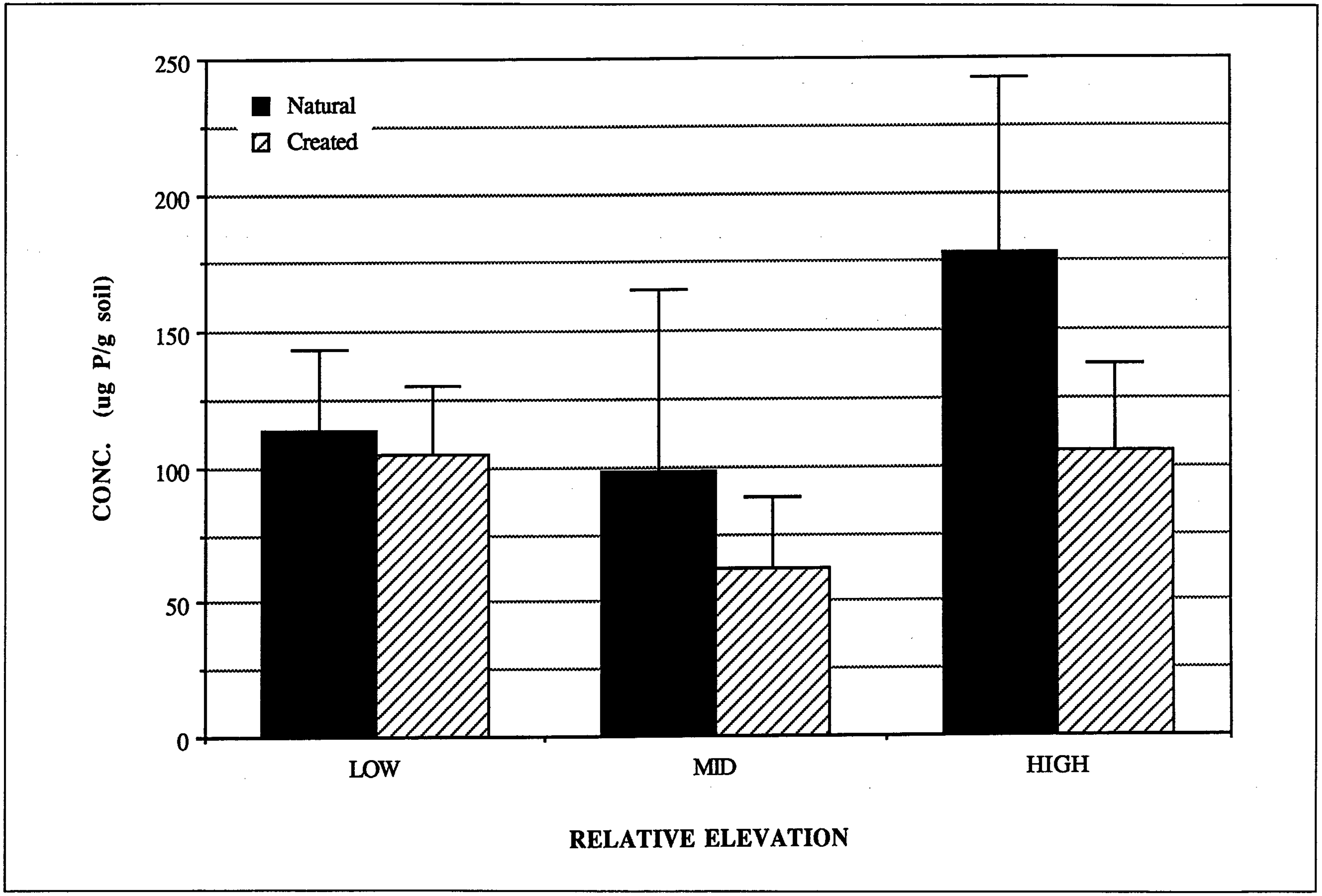

Figure A26. Comparison by elevation of mean (1 std. dev.) iron- and aluminum-bound phosphorus concentrations in old natural and created wetland soils (November 1993)

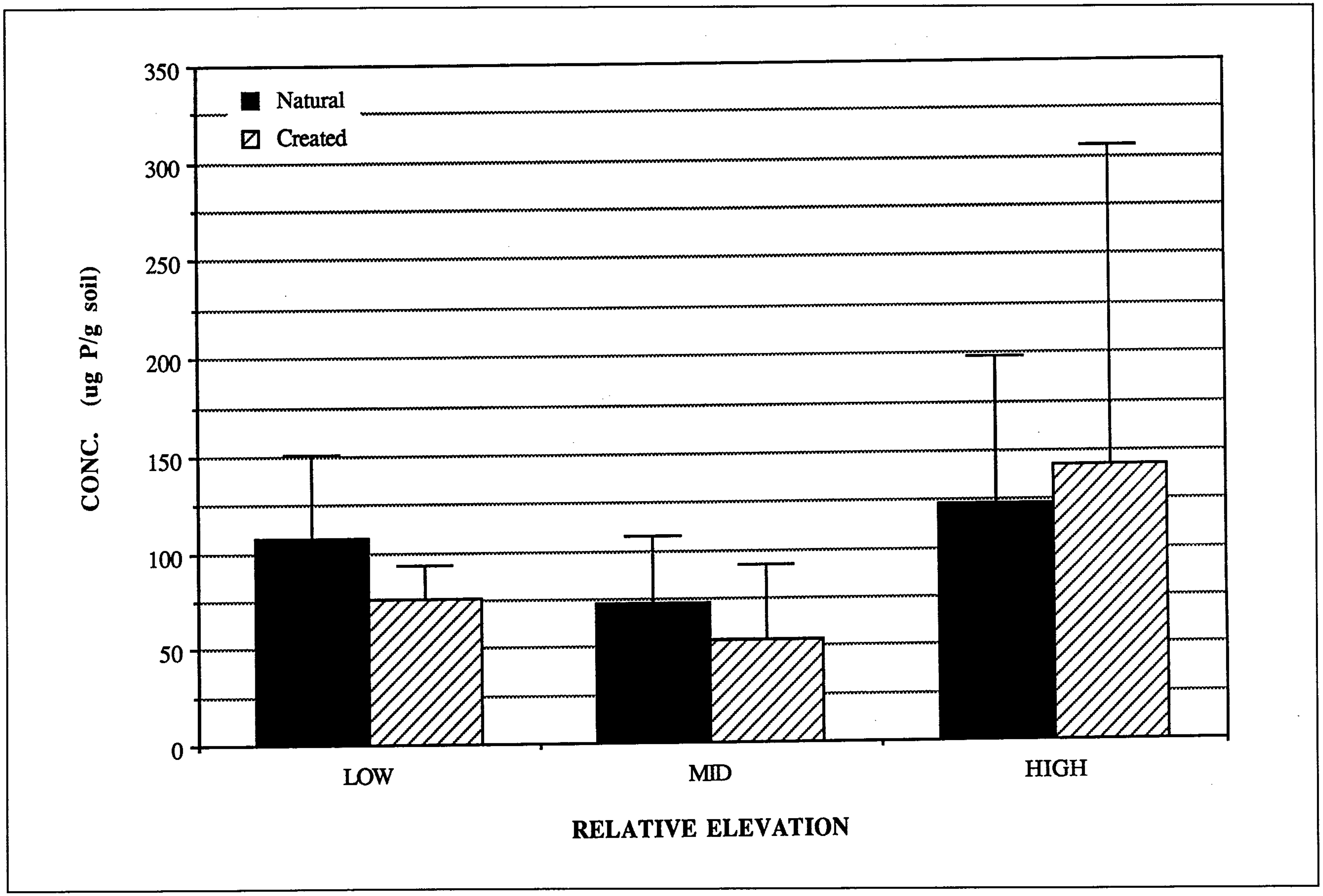

Figure A27. Comparison by elevation of mean (1 std. dev.) reductant-soluble phosphorus concentrations in old natural and created wetland soils (November 1993)

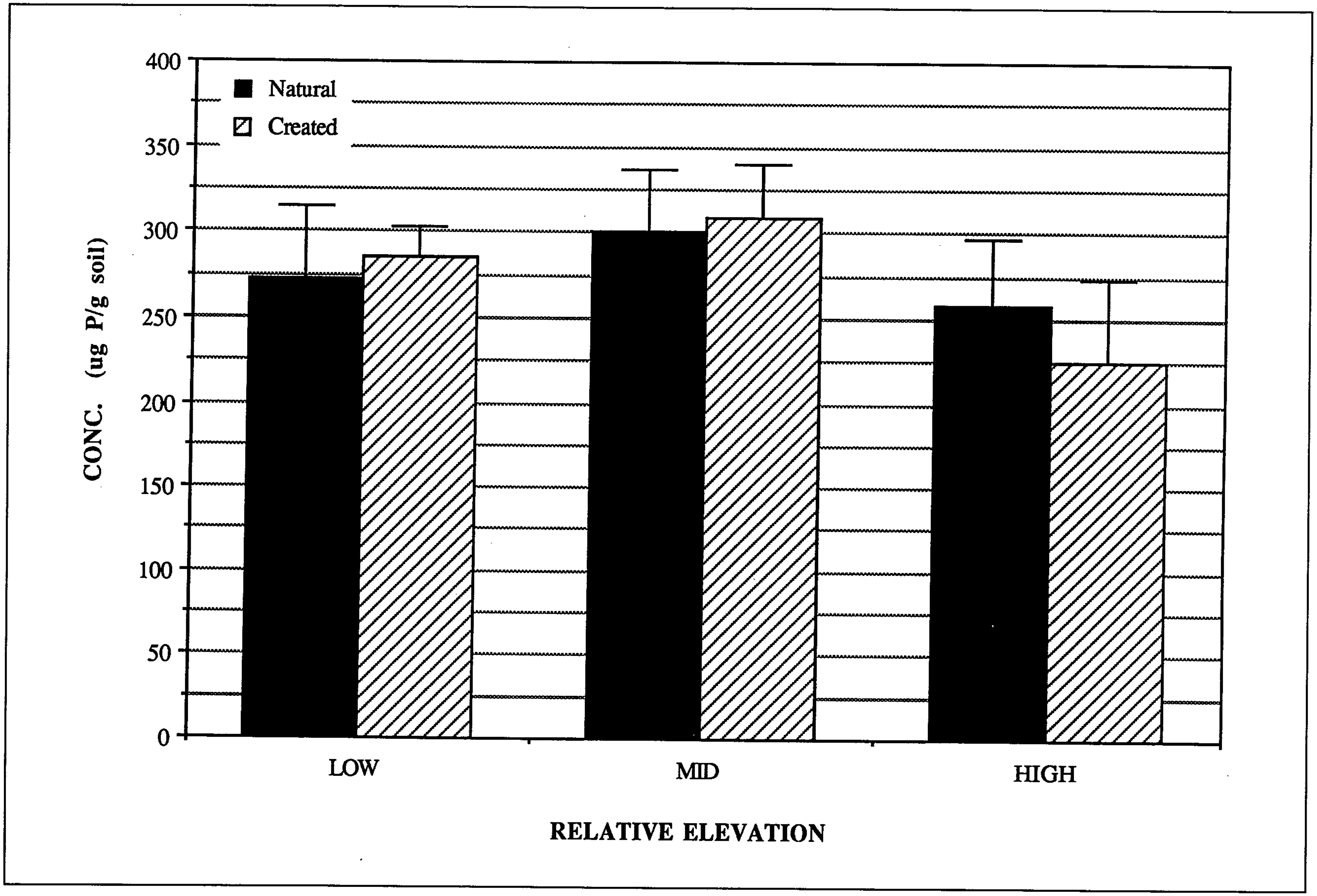

Figure A28. Comparison by elevation of mean (1 std. dev.) calcium-bound phosphorus concentrations in old natural and created wetland soils (November 1993)

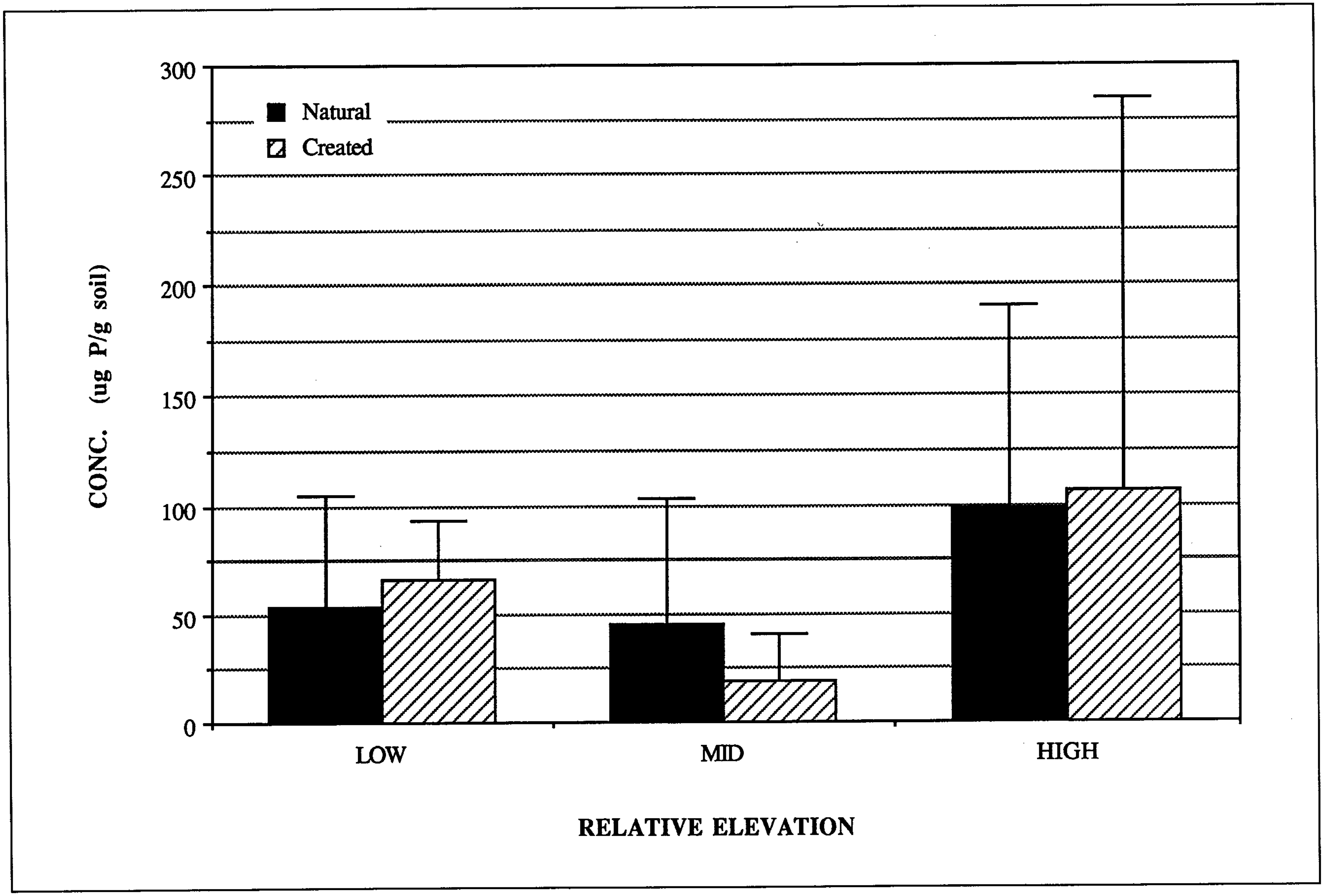

Figure A29. Comparison by elevation of mean (1 std. dev.) organic phosphorus concentrations in old natural and created wetland soils (November 1993)

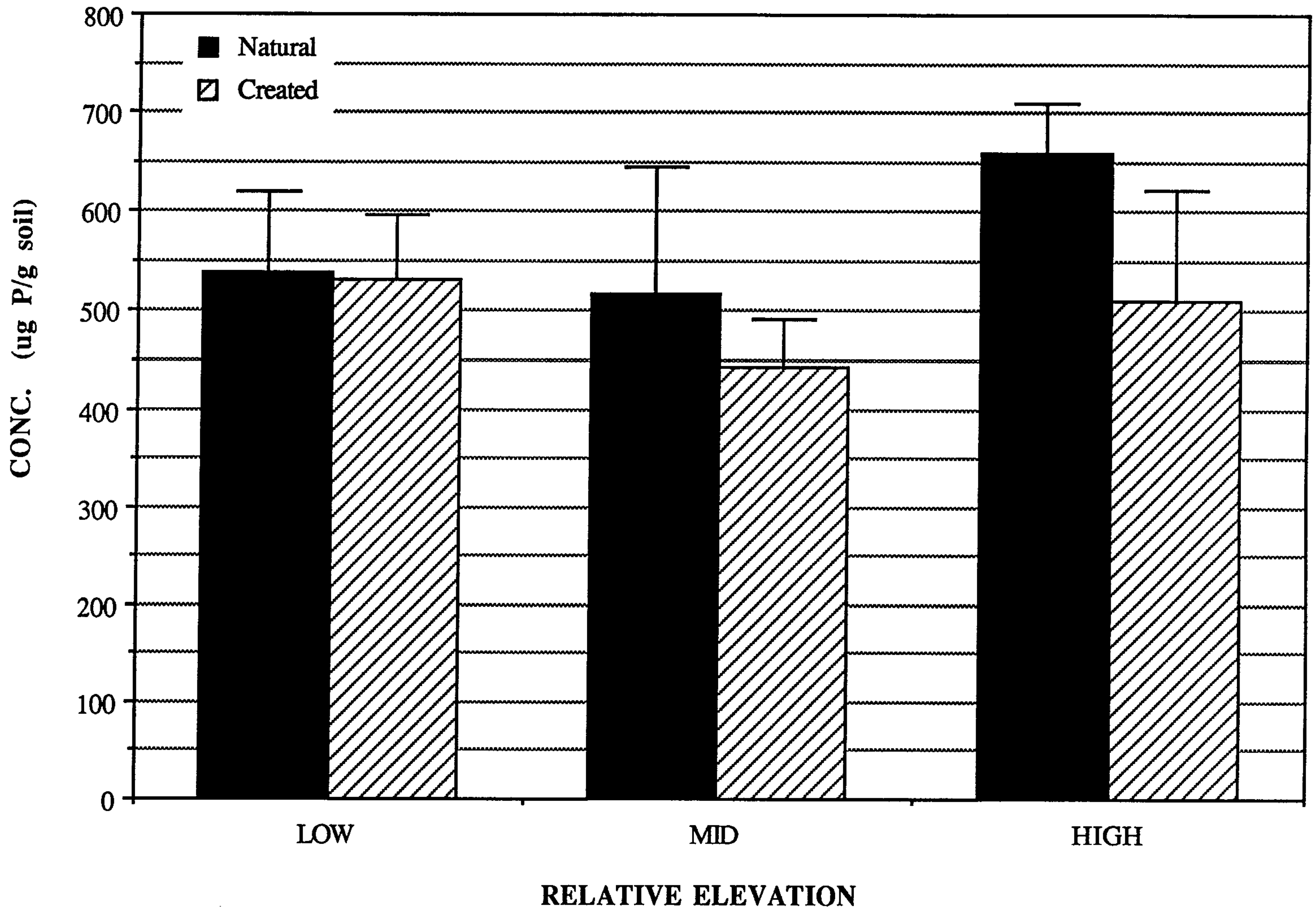

Figure A30. Comparison by elevation of mean (1 std. dev.) total soil phosphorus concentrations in old natural and created wetland soils (November 1993)

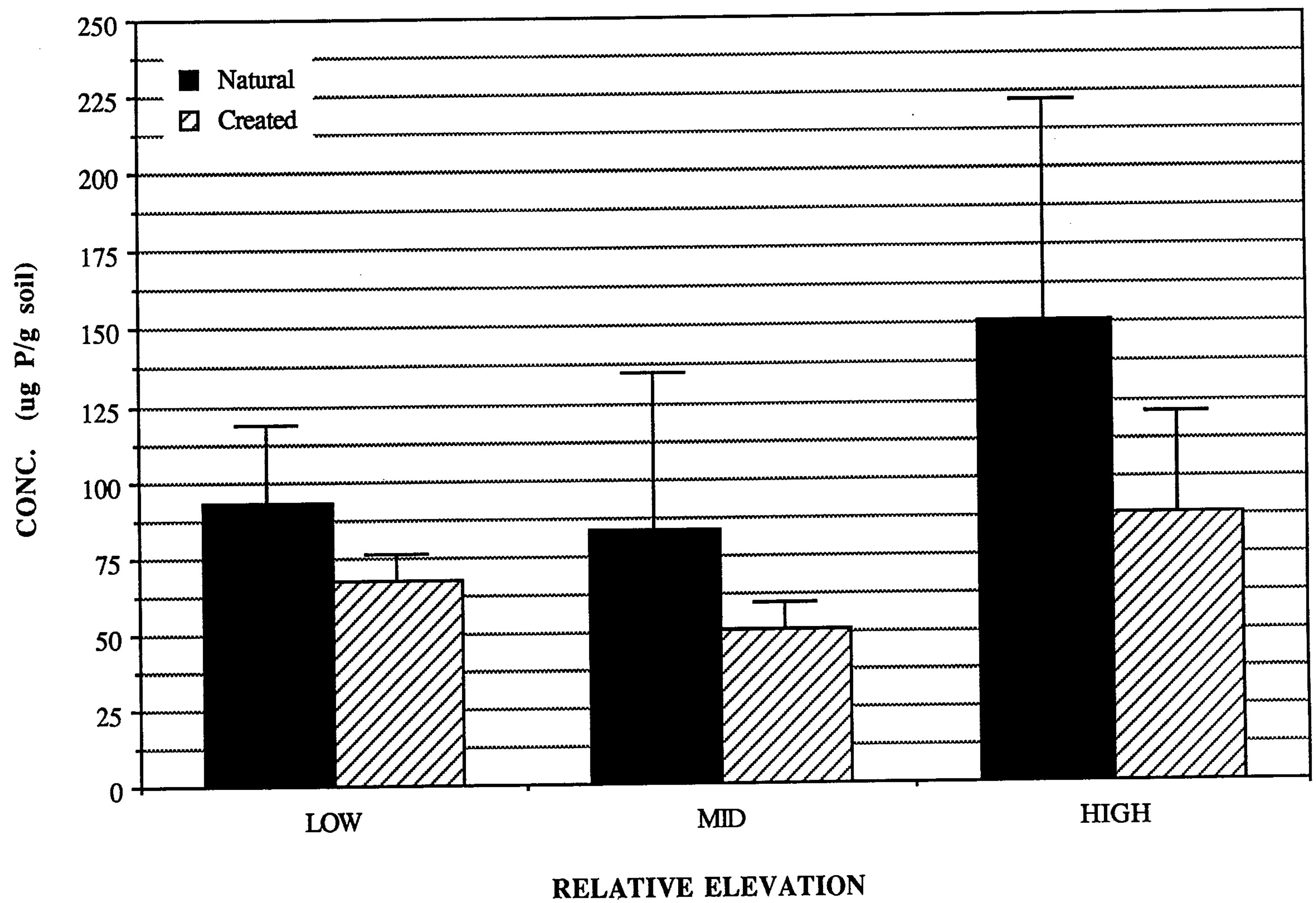

Figure A31. Comparison by elevation of mean (1 std. dev.) iron- and aluminum-bound phosphorus concentrations in old natural and created wetland soils (December 1993)

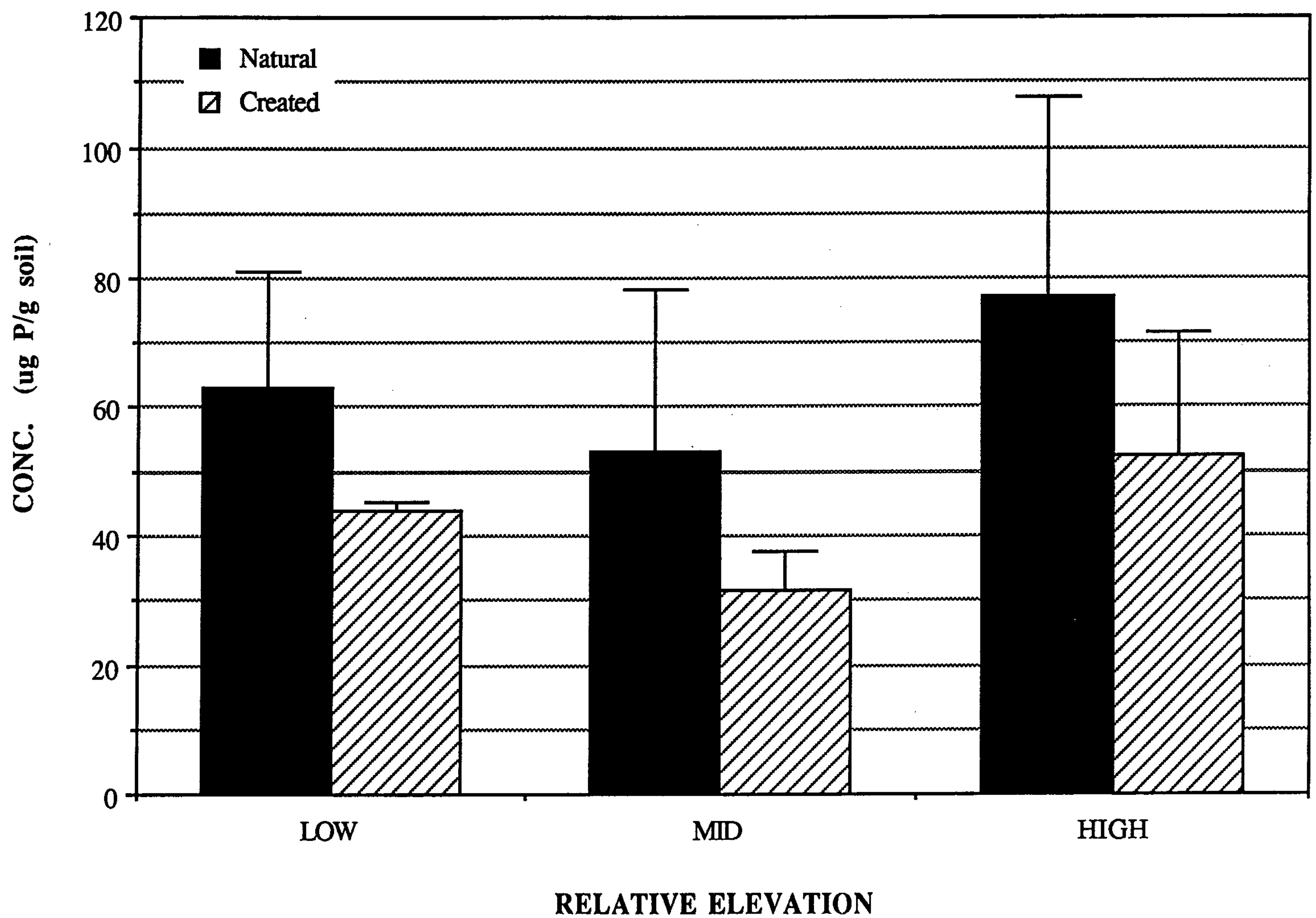

Figure A32. Comparison by elevation of mean (1 std. dev.) reductant-soluble phosphorus concentrations in old natural and created wetland soils (December 1993)

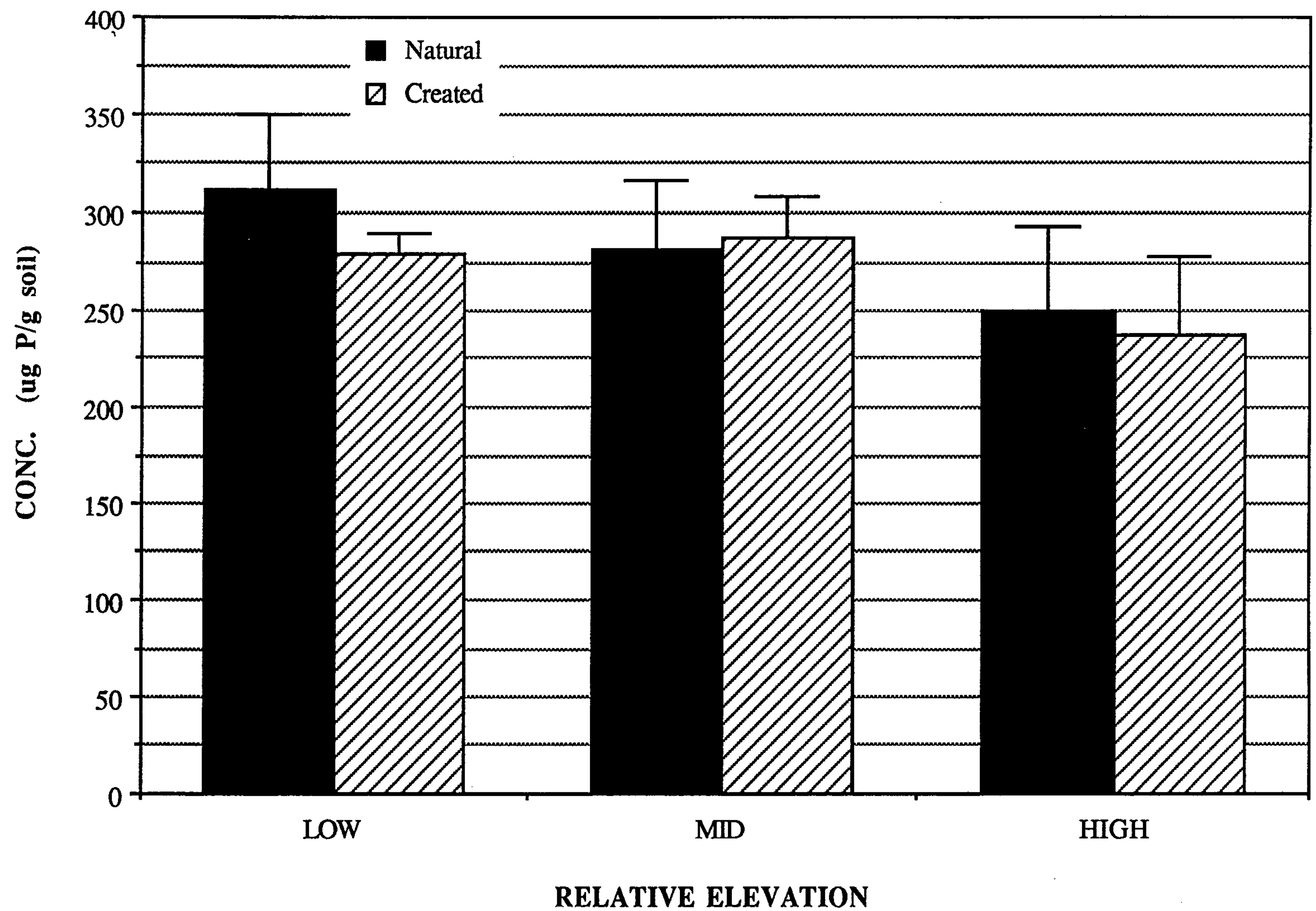

Figure A33. Comparison by elevation of mean (1 std. dev.) calcium-bound phosphorus concentrations in old natural and created wetland soils (December 1993)

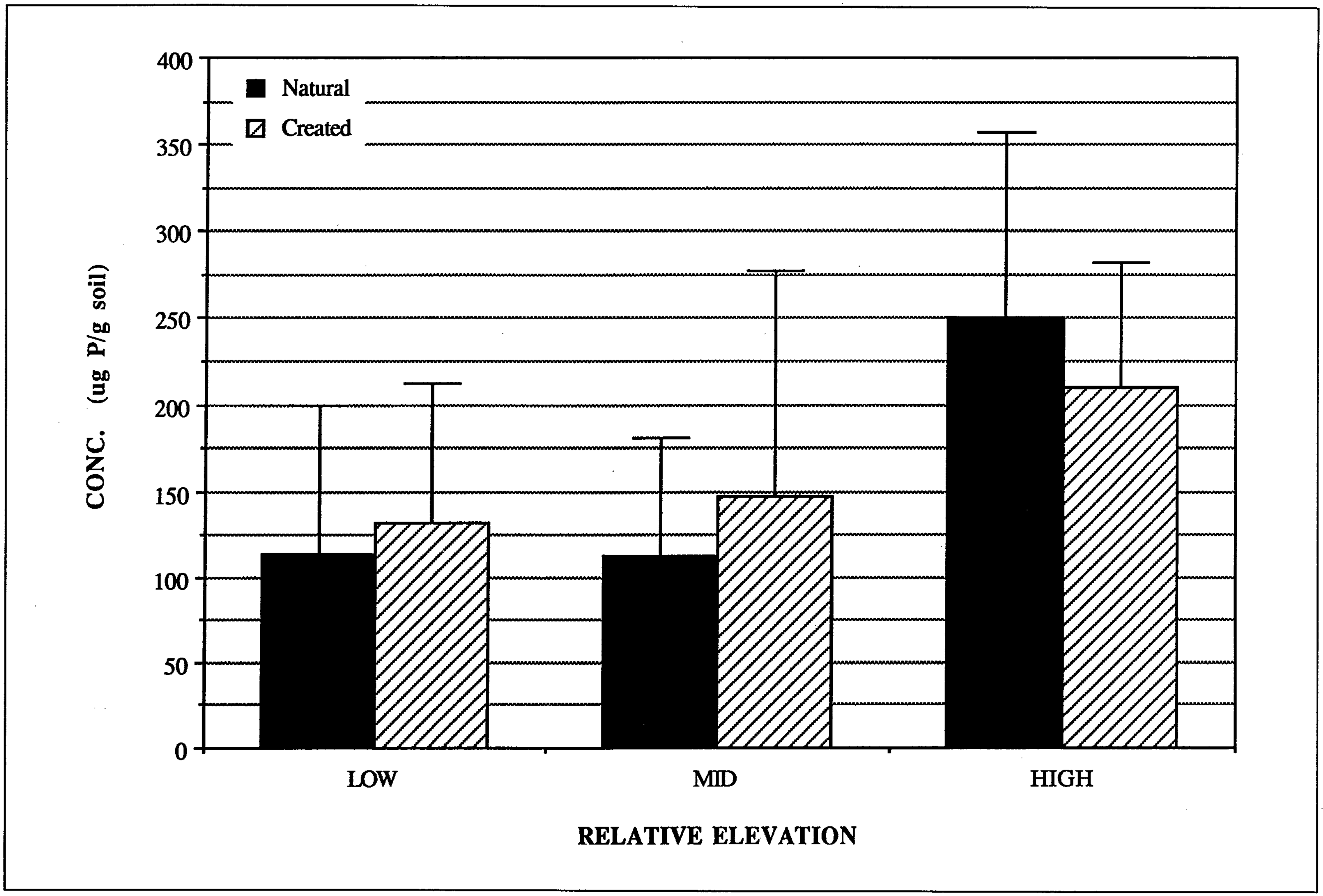

Figure A34. Comparison by elevation of mean (1 std. dev.) organic phosphorus concentrations in old natural and created wetland soils (December 1993)

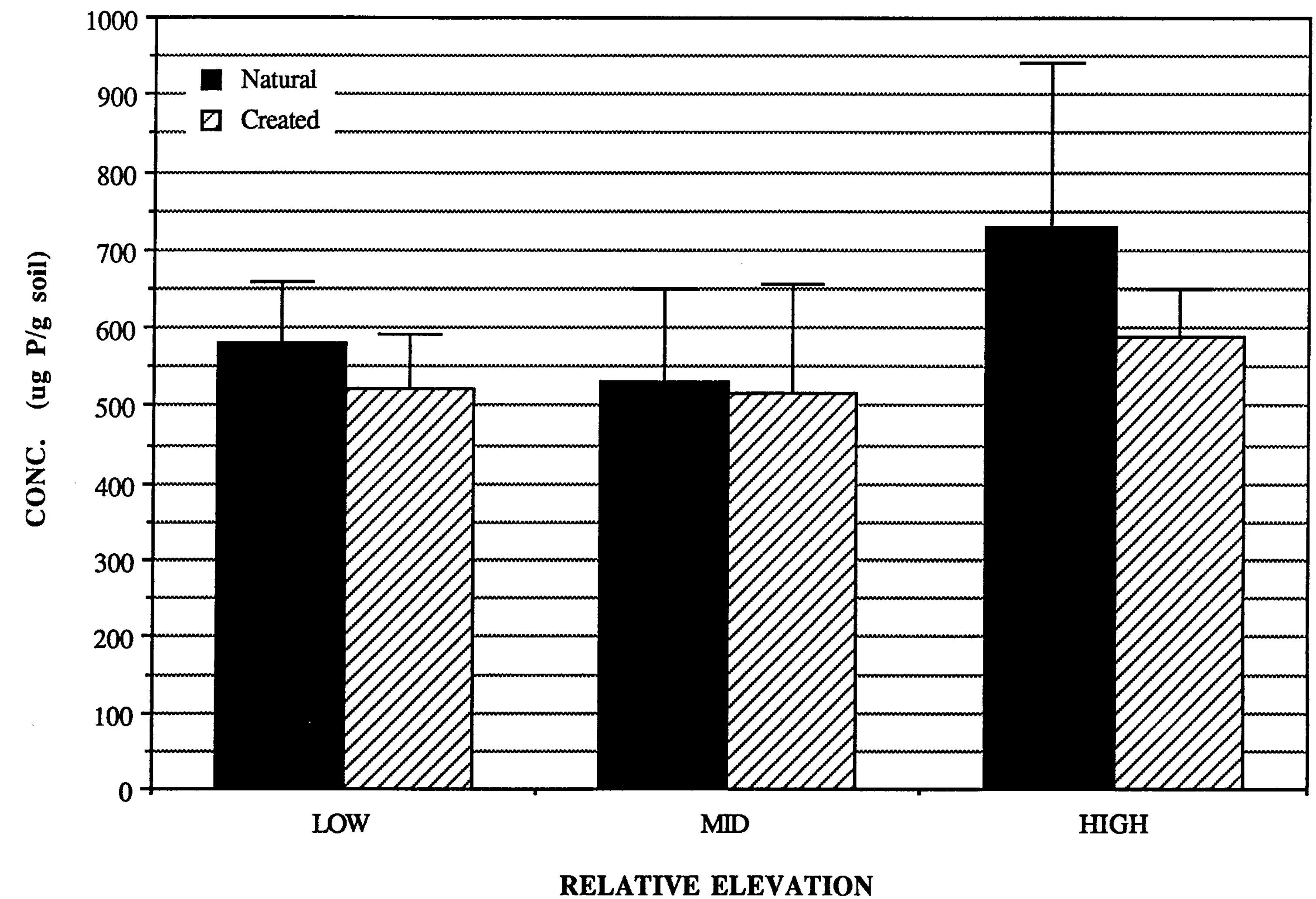

Figure A35. Comparison by elevation of mean (1 std. dev.) total soil phosphorus concentrations in old natural and created wetland soils (December 1993)

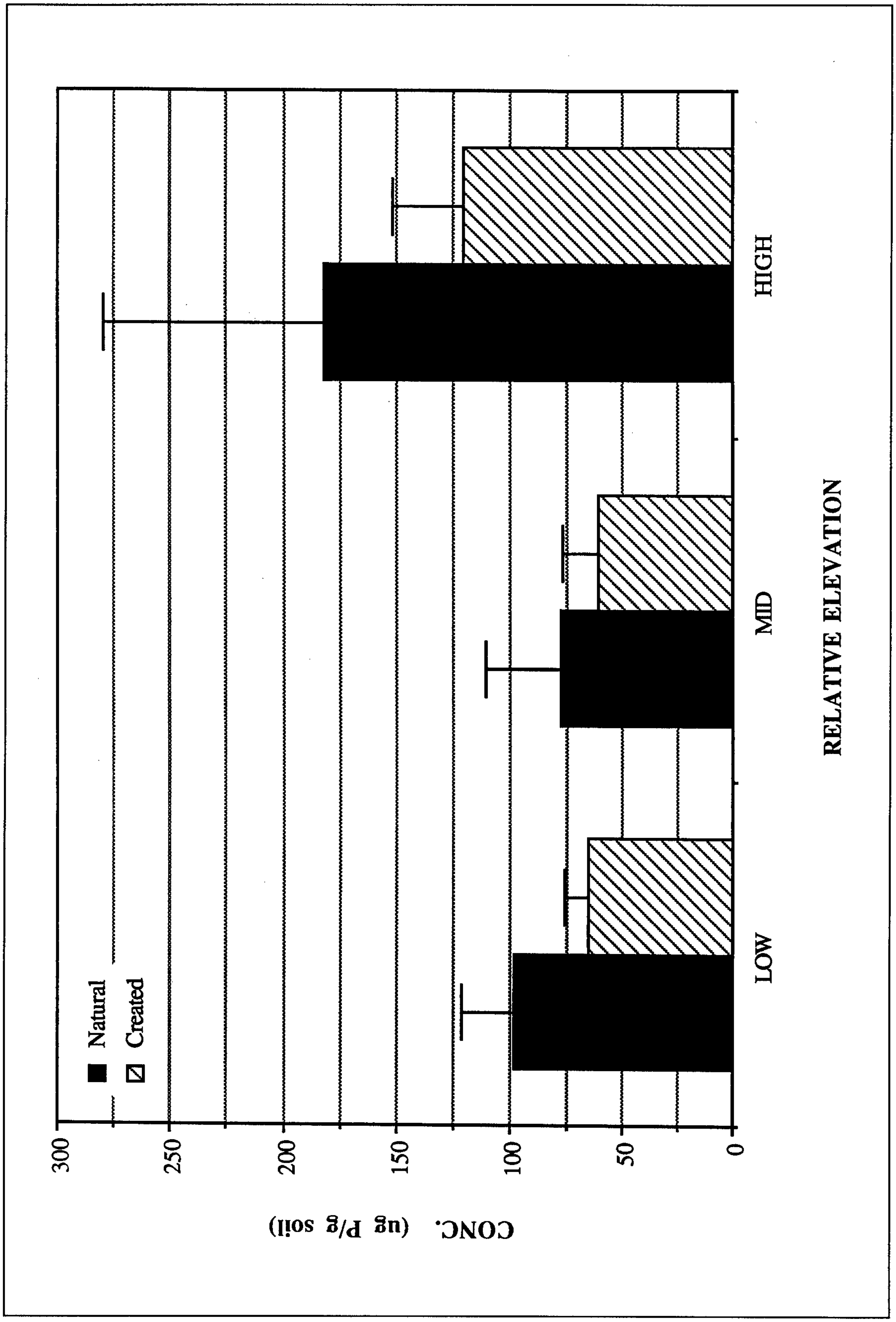

Figure A36. Comparison by elevation of mean (1 std. dev.) iron- and aluminum-bound phosphorus concentrations in old natural and created wetland soils (January 1994)

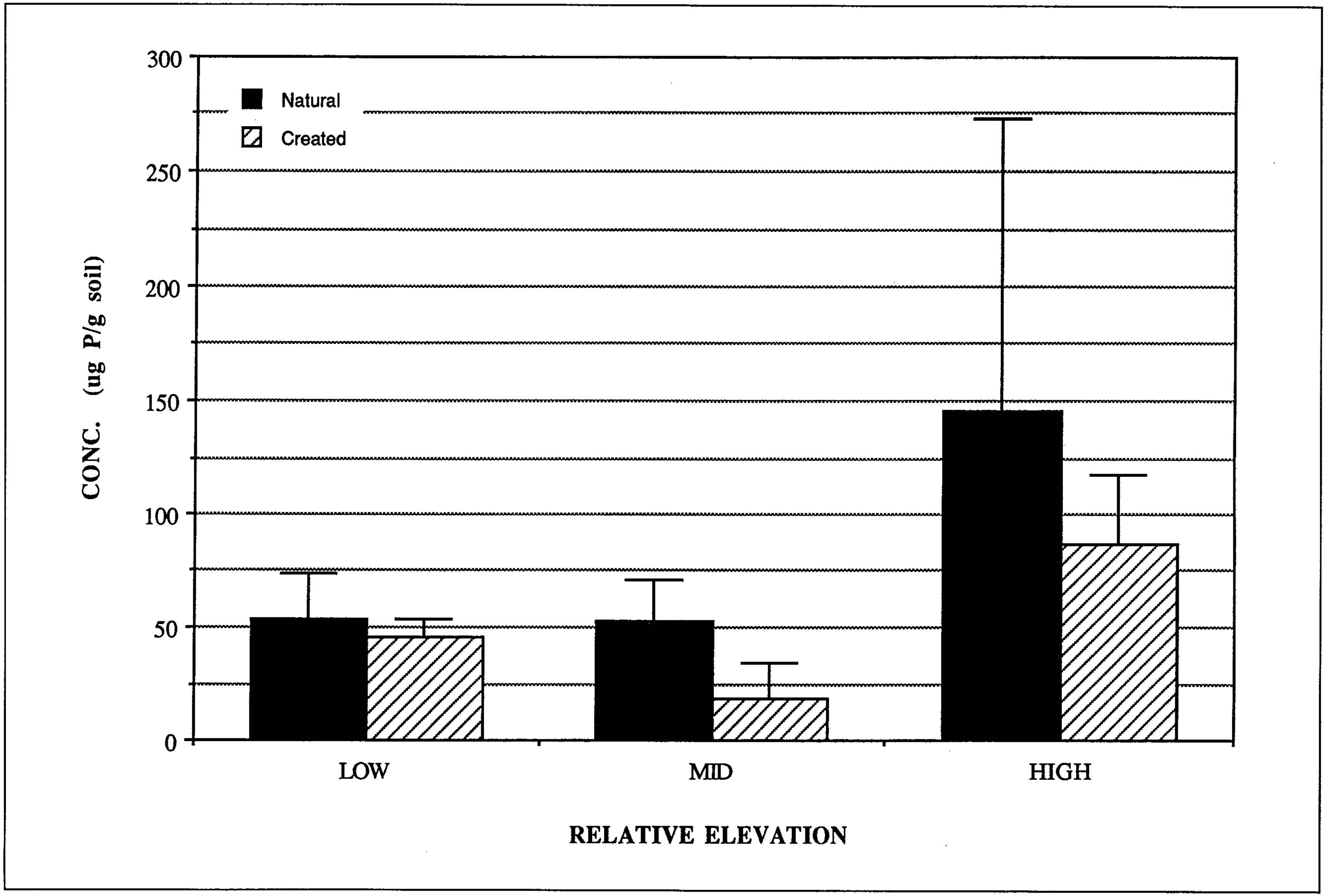

Figure A37. Comparison by elevation of mean (1 std. dev.) reductant-soluble phosphorus concentrations in old natural and created wetland soils (January 1994)

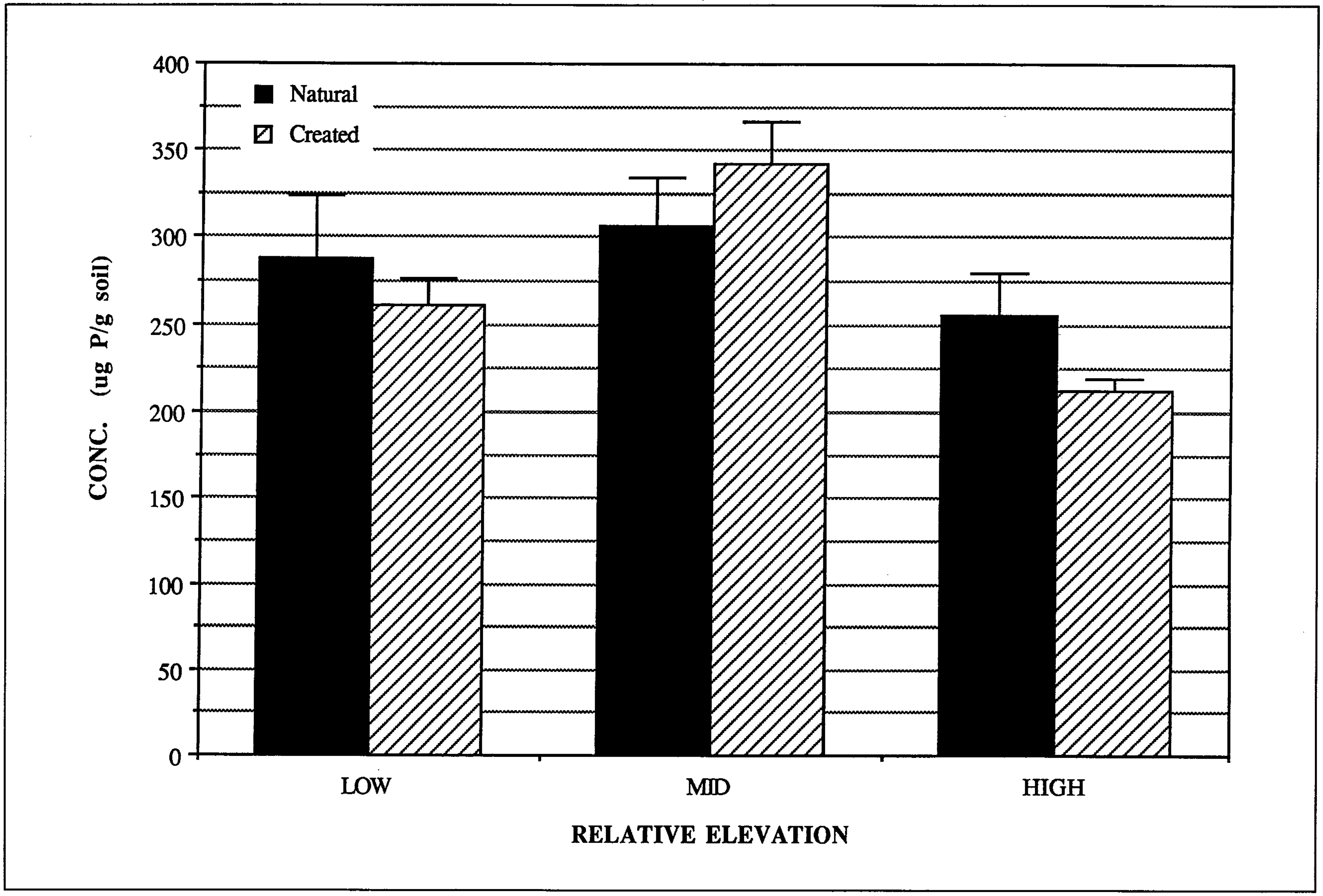

Figure A38. Comparison by elevation of mean (1 std. dev.) calcium-bound phosphorus concentrations in old natural and created wetland soils (January 1994)

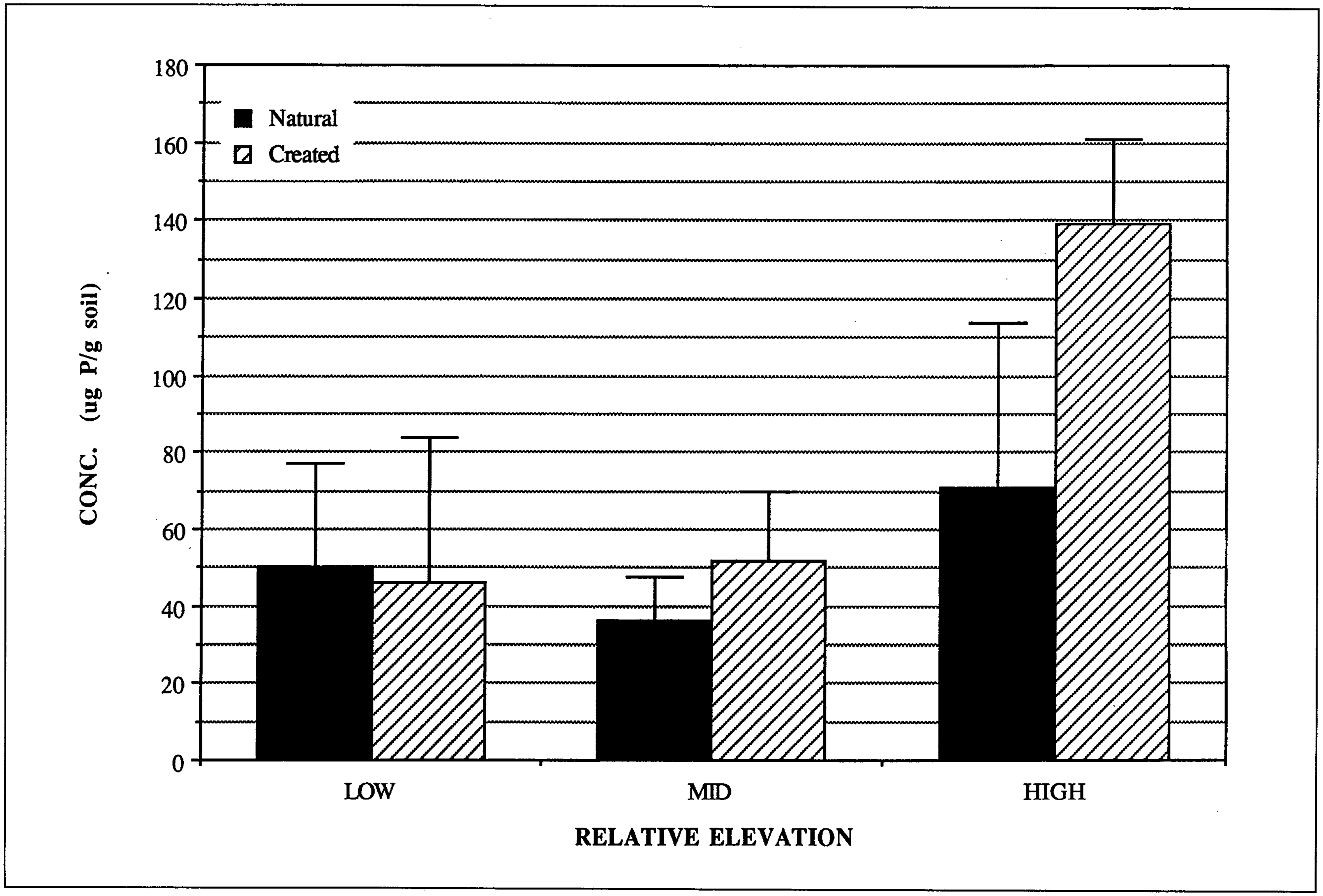

Figure A39. Comparison by elevation of mean (1 std. dev.) organic phosphorus concentrations in old natural and created wetland soils (January 1994)

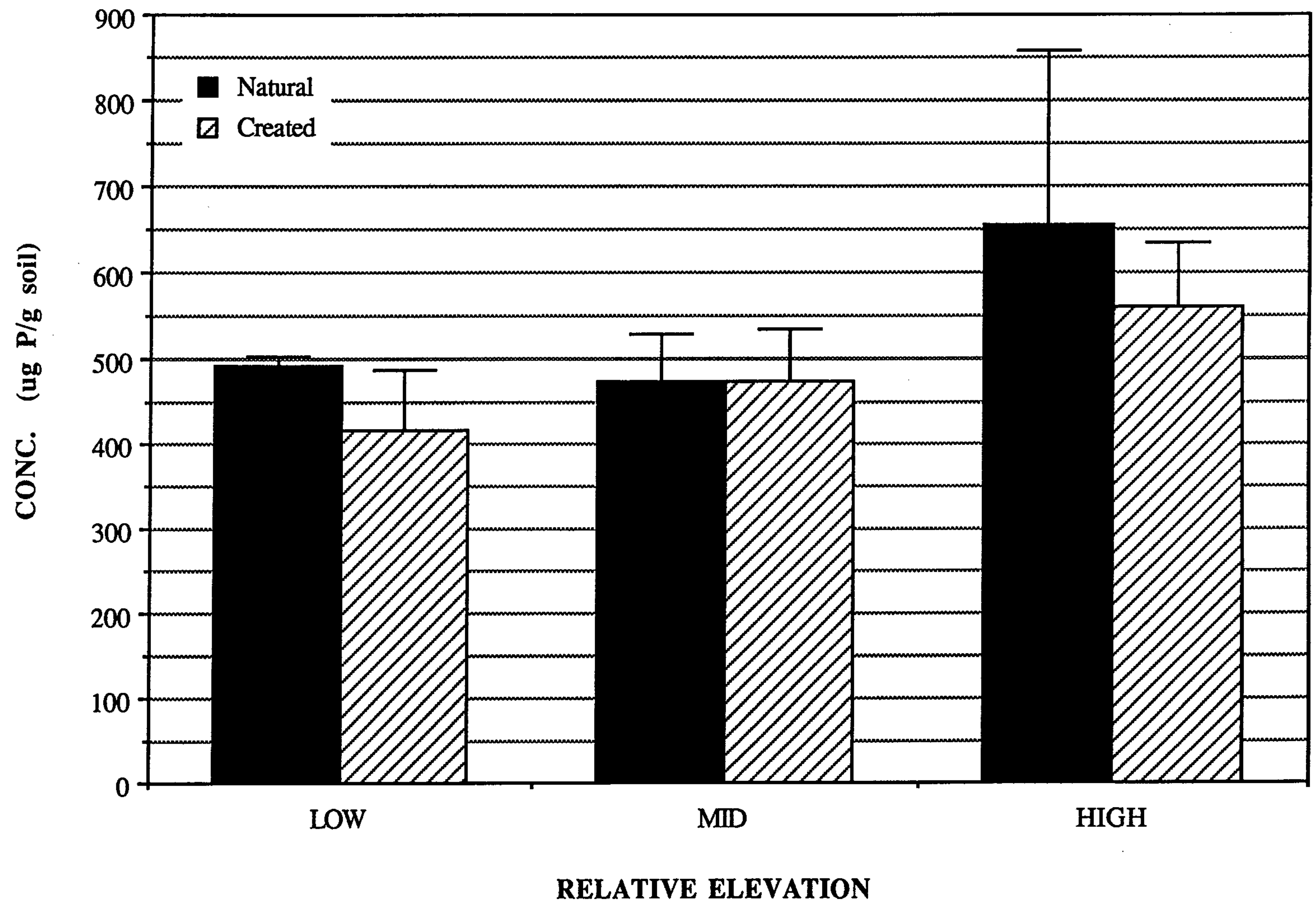

Figure A40. Comparison by elevation of mean (1 std. dev.) total soil phosphorus concentrations in old natural and created wetland soils (January 1994)

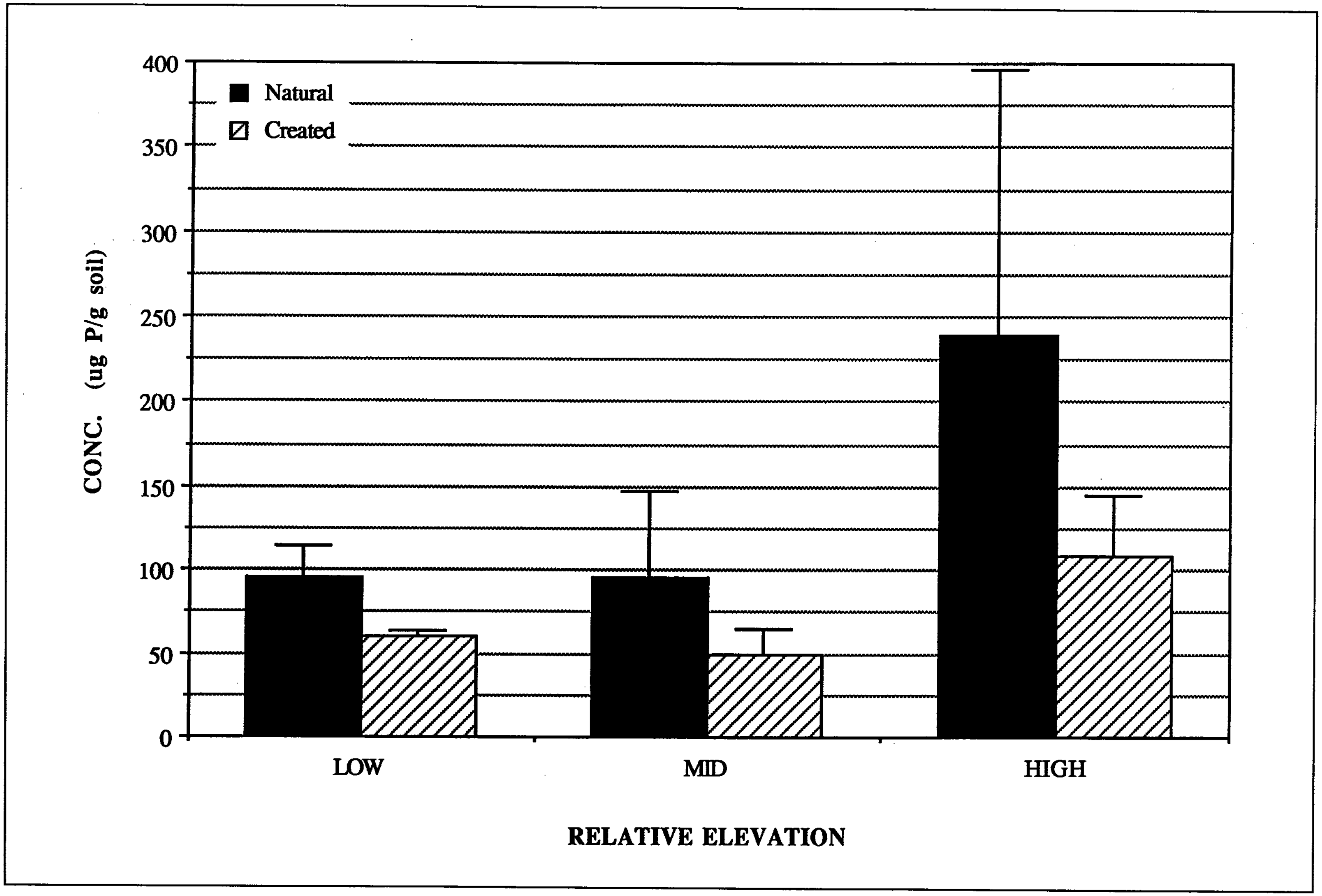

Figure A41. Comparison by elevation of mean (1 std. dev.) iron- and aluminum-bound phosphorus concentrations in old natural and created wetland soils (May 1994)

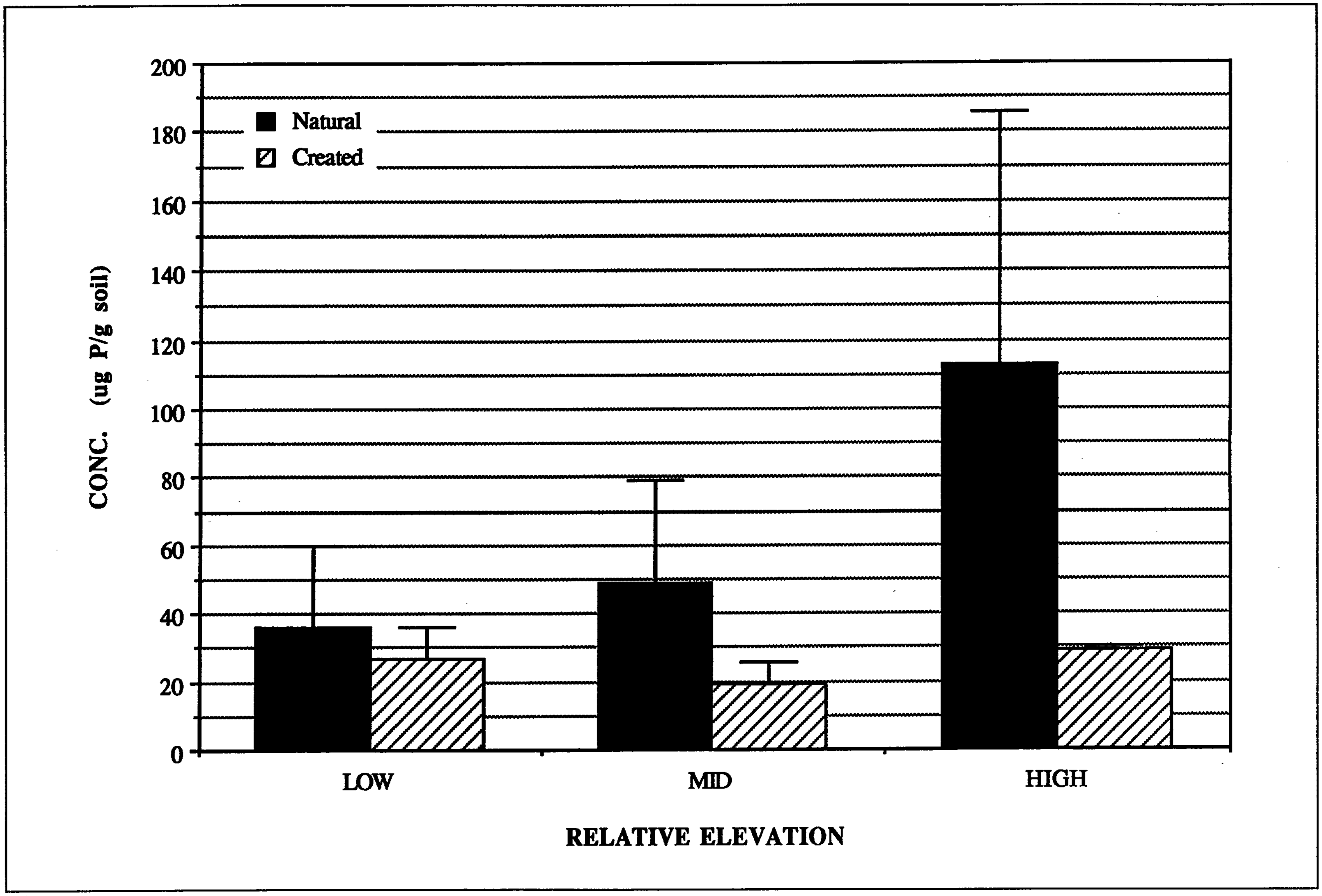

Figure A42. Comparison by elevation of mean (1 std. dev.) reductant-soluble phosphorus concentrations in old natural and created wetland soils (May 1994)

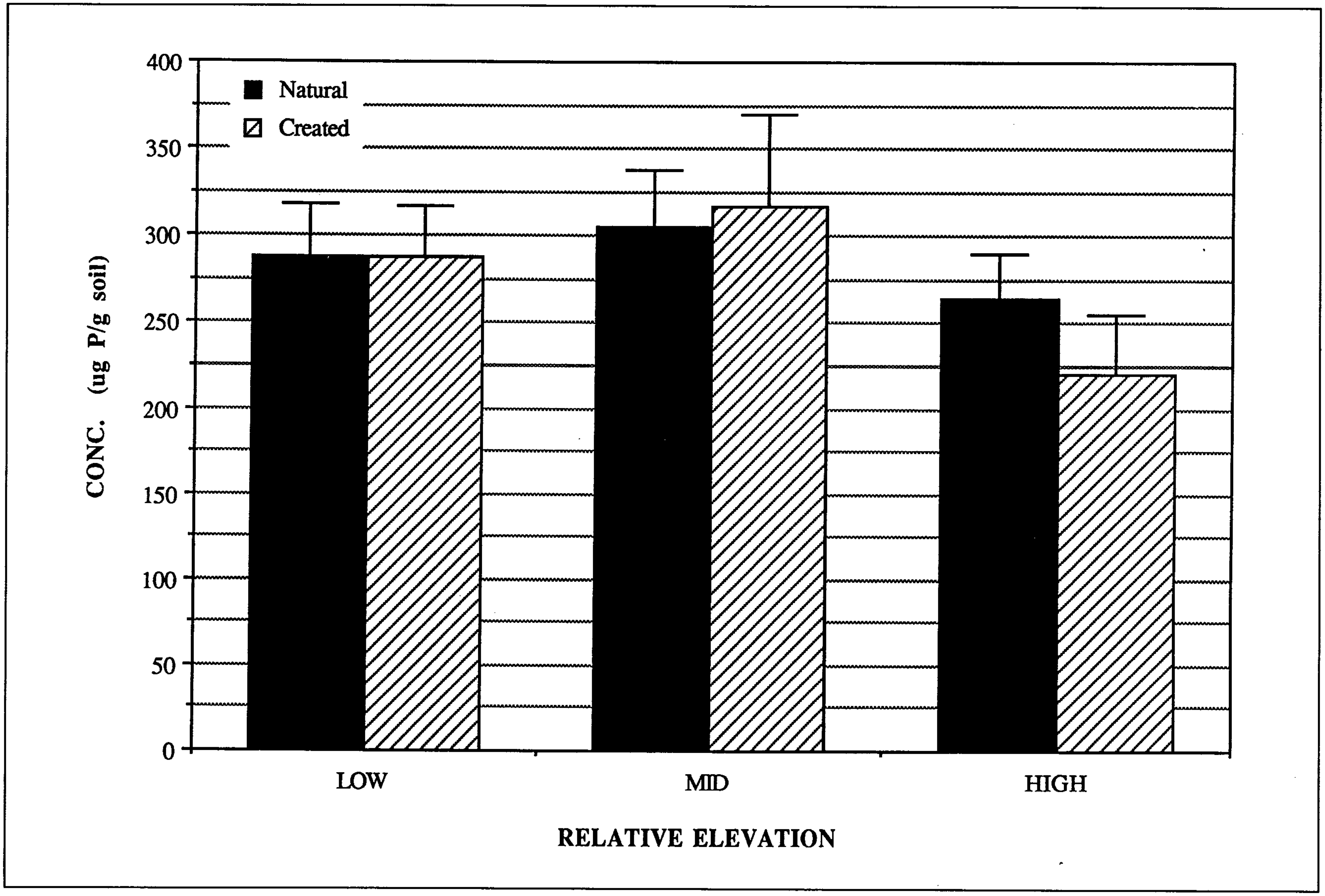

Figure A43. Comparison by elevation of mean (1 std. dev.) calcium-bound phosphorus concentrations in old natural and created wetland soils (May 1994)

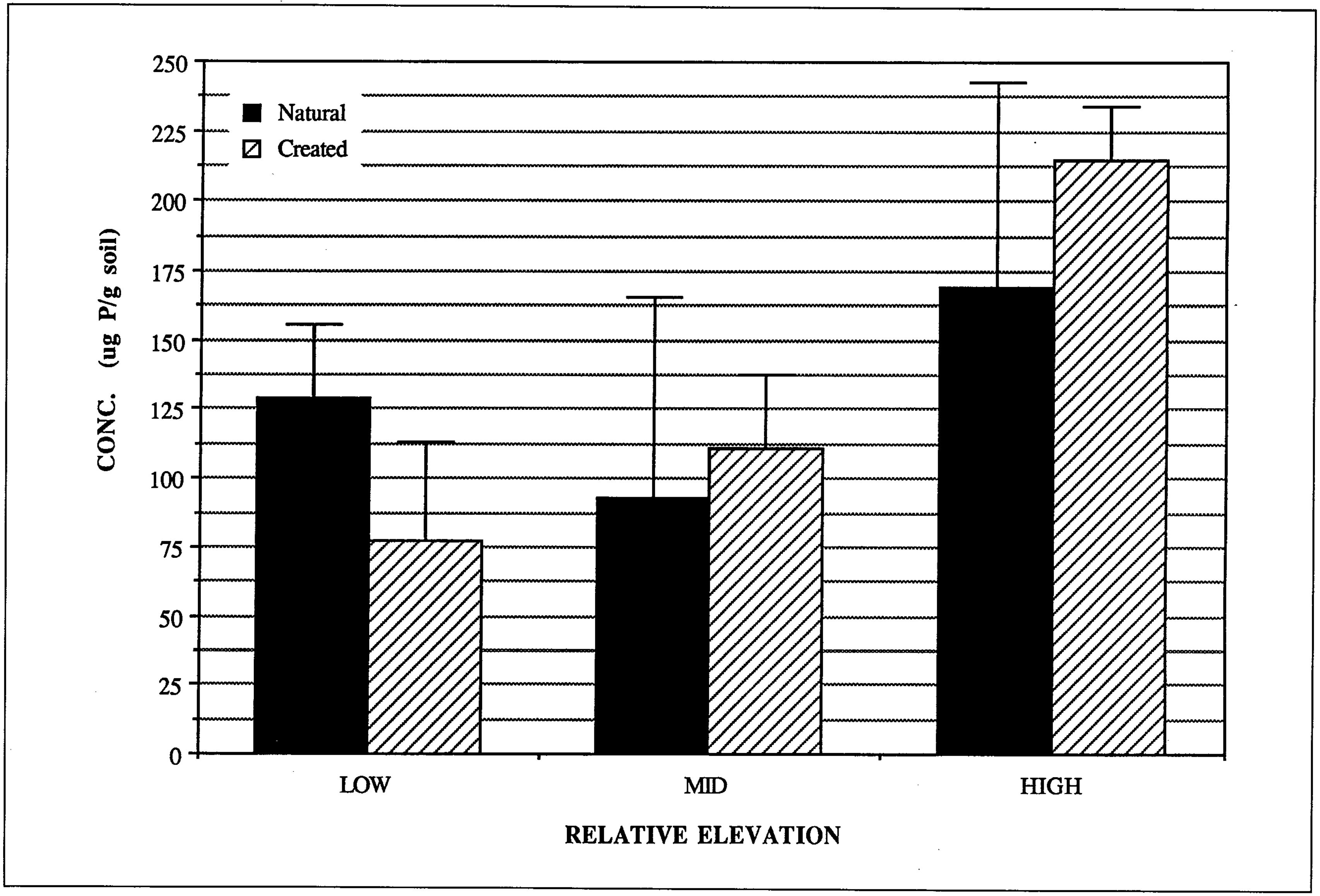

Figure A44. Comparison by elevation of mean (1 std. dev.) organic phosphorus concentrations in old natural and created wetland soils (May 1994)

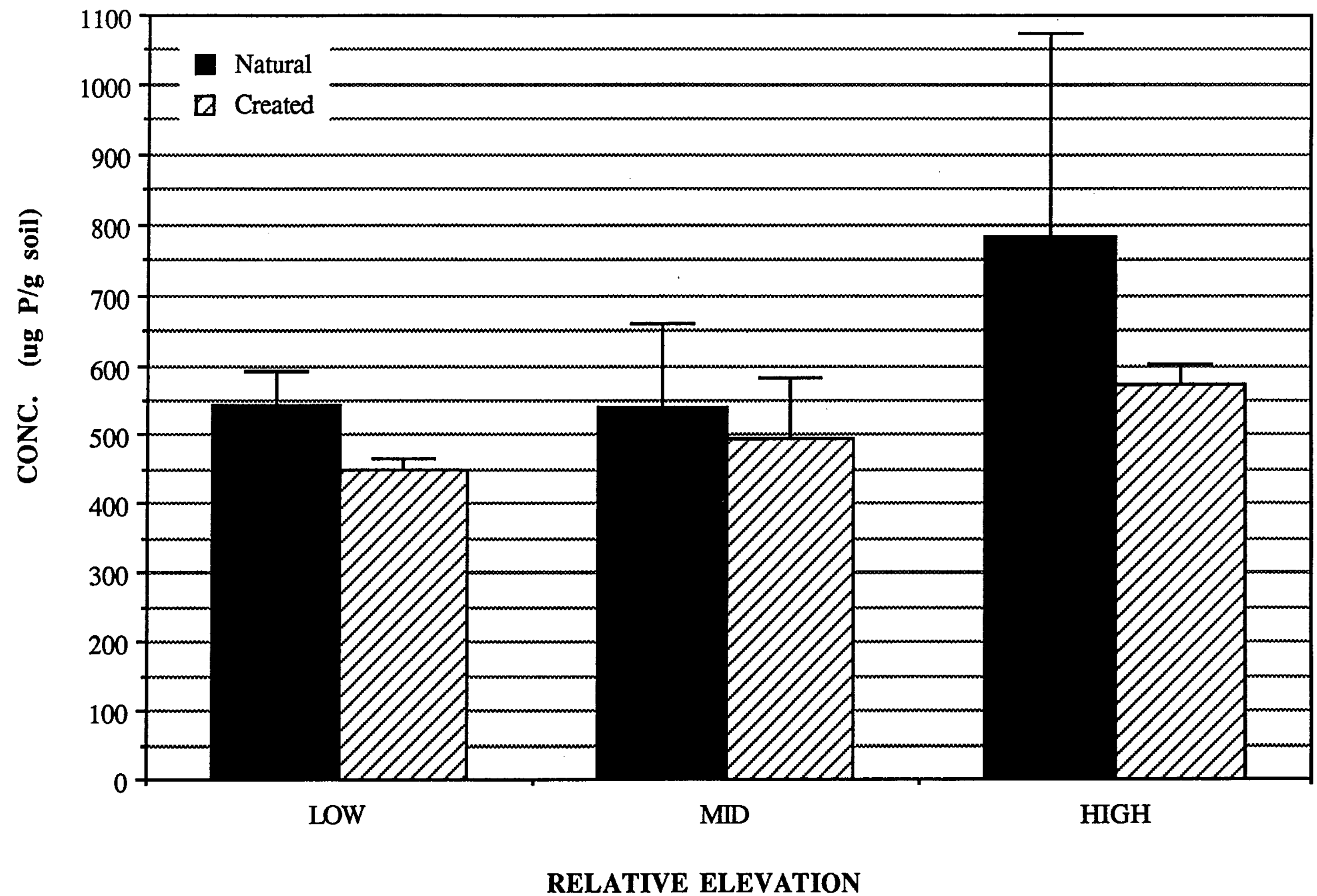

Figure A45. Comparison by elevation of mean (1 std. dev.) total soil phosphorus concentrations in old natural and created wetland soils (May 1994)

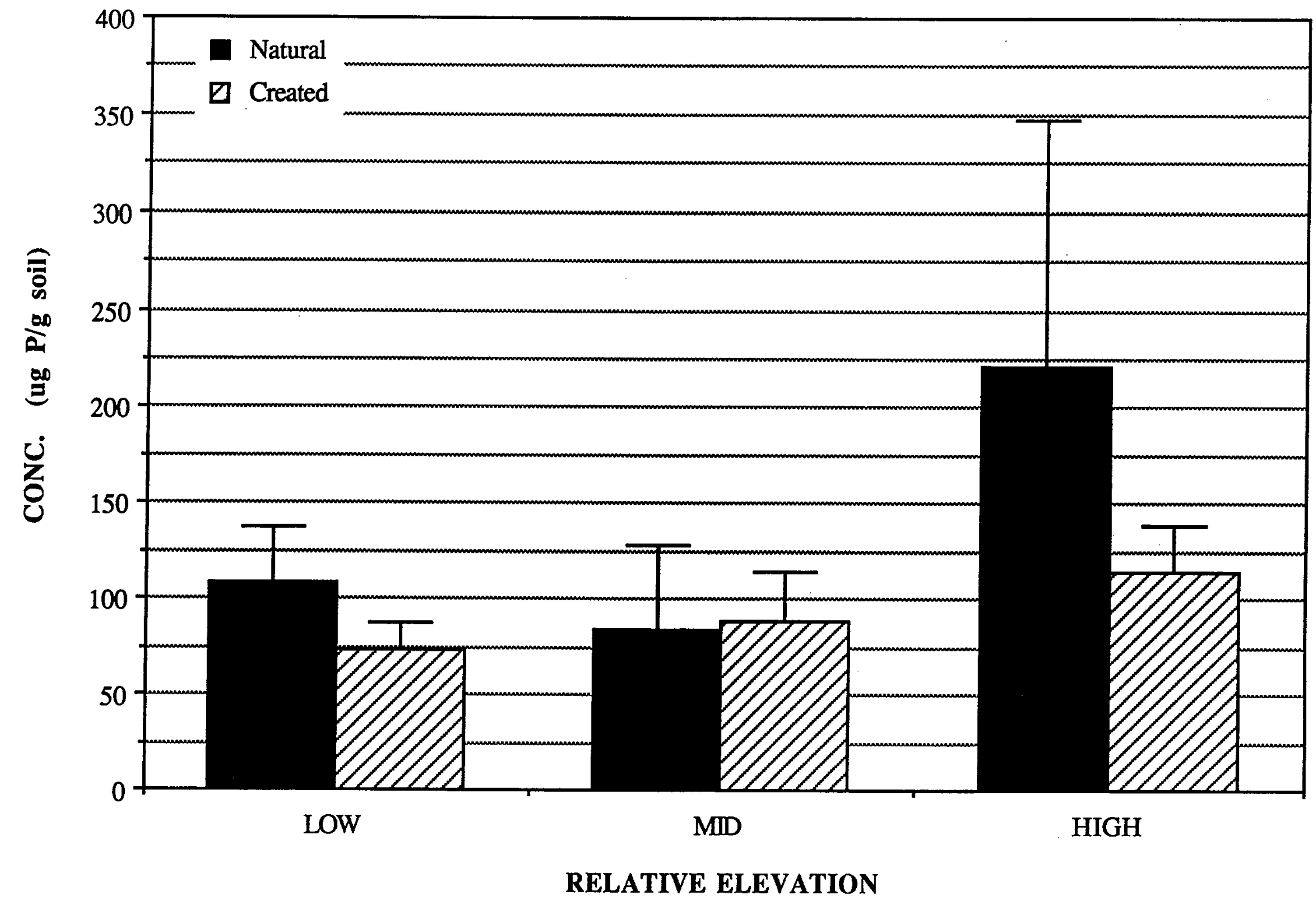

Figure A46. Comparison by elevation of mean (1 std. dev.) iron- and aluminum-bound phosphorus concentrations in old natural and created wetland soils (July 1994)

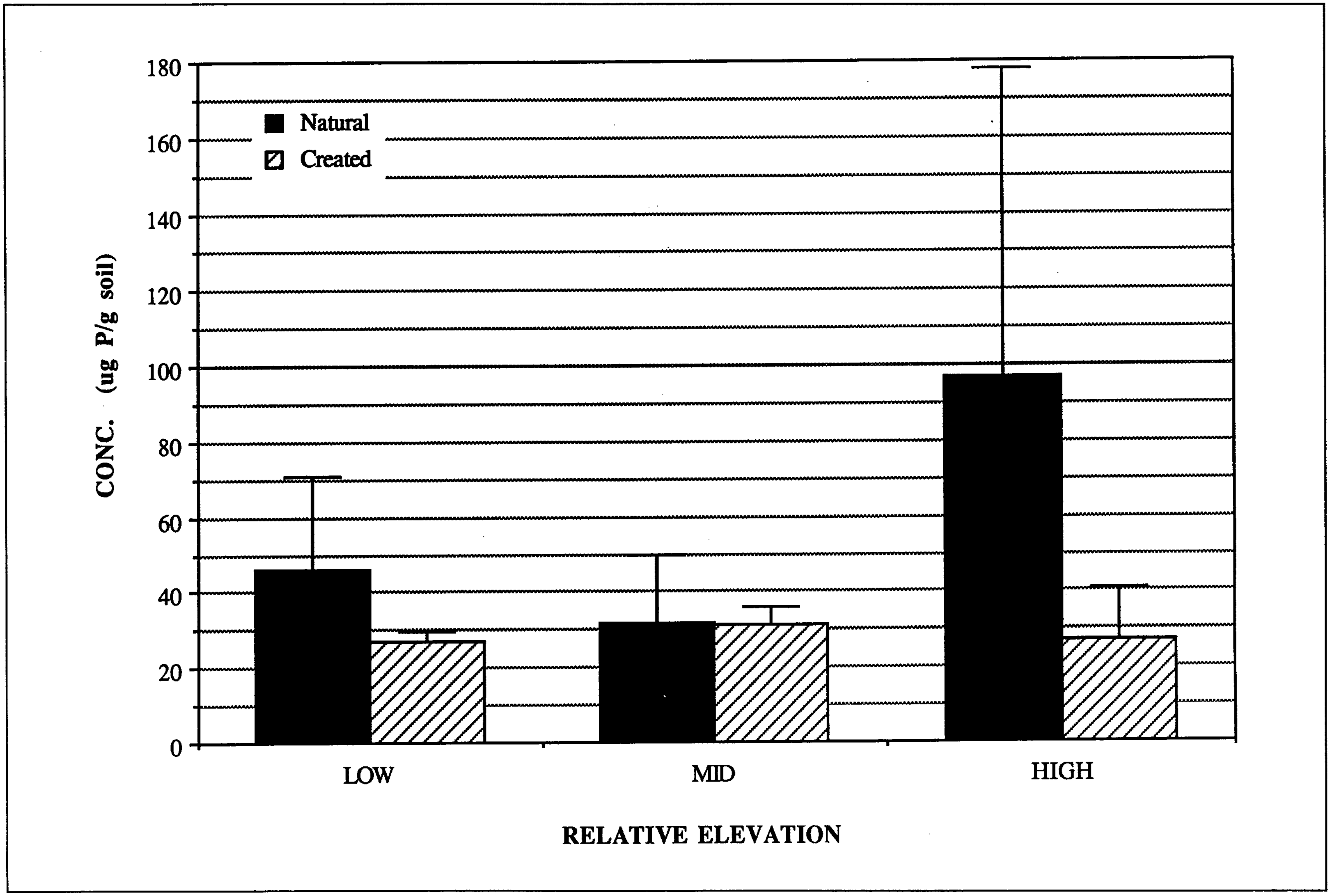

Figure A47. Comparison by elevation of mean (1 std. dev.) reductant-soluble phosphorus concentrations in old natural and created wetland soils (July 1994)

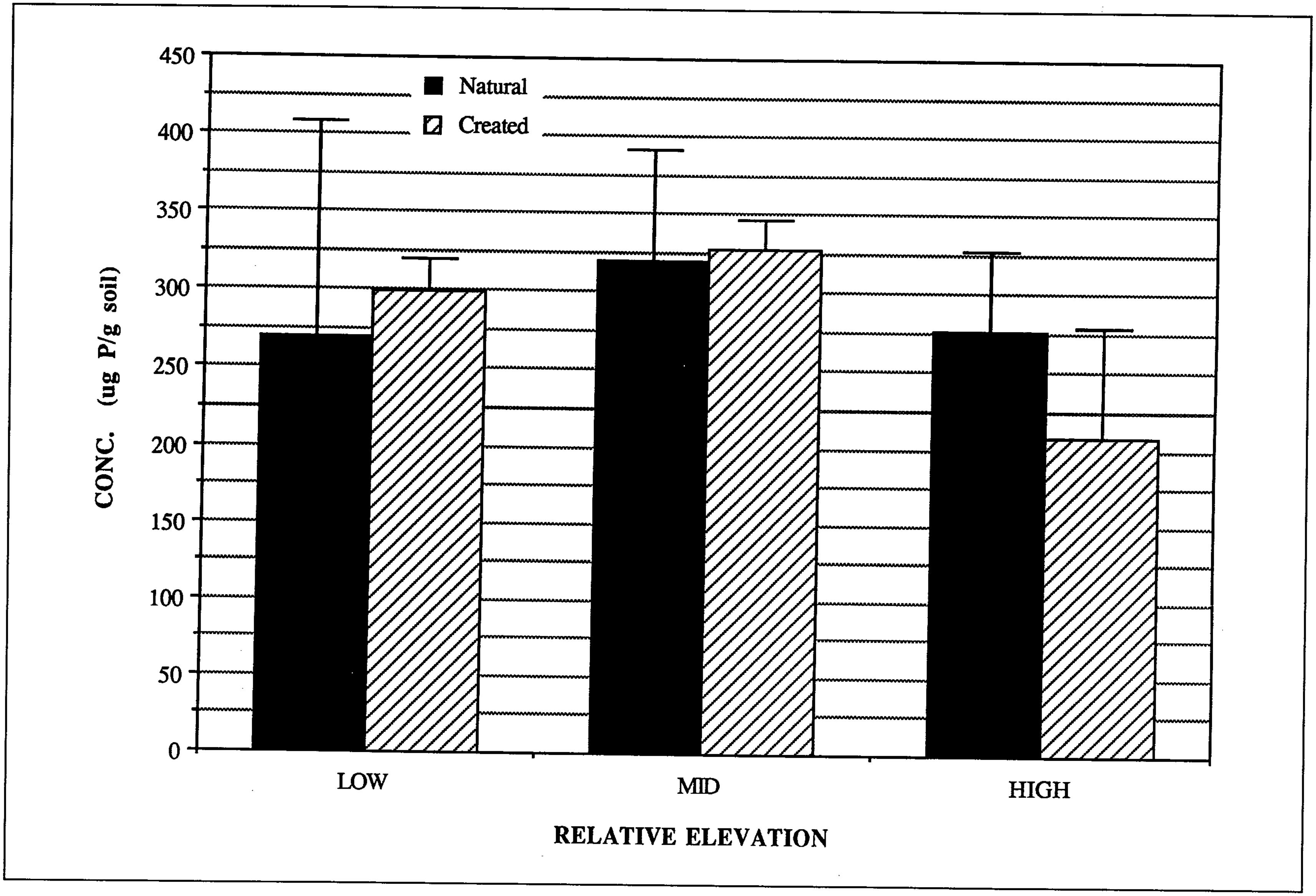

Figure A48. Comparison by elevation of mean (1 std. dev.) calcium-bound phosphorus concentrations in old natural and created wetland soils (July 1994)

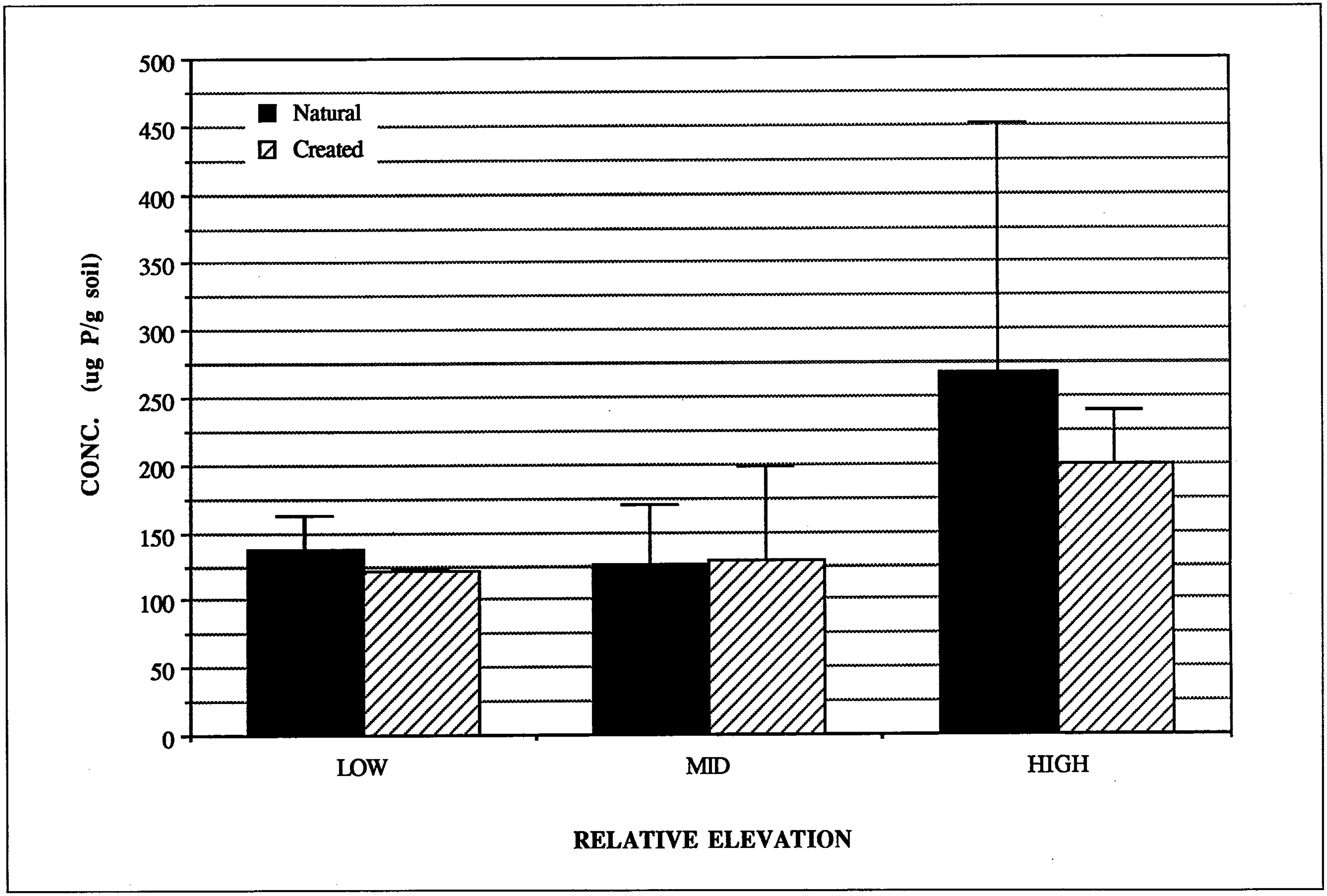

Figure A49. Comparison by elevation of mean (1 std. dev.) organic phosphorus concentrations in old natural and created wetland soils (July 1994)

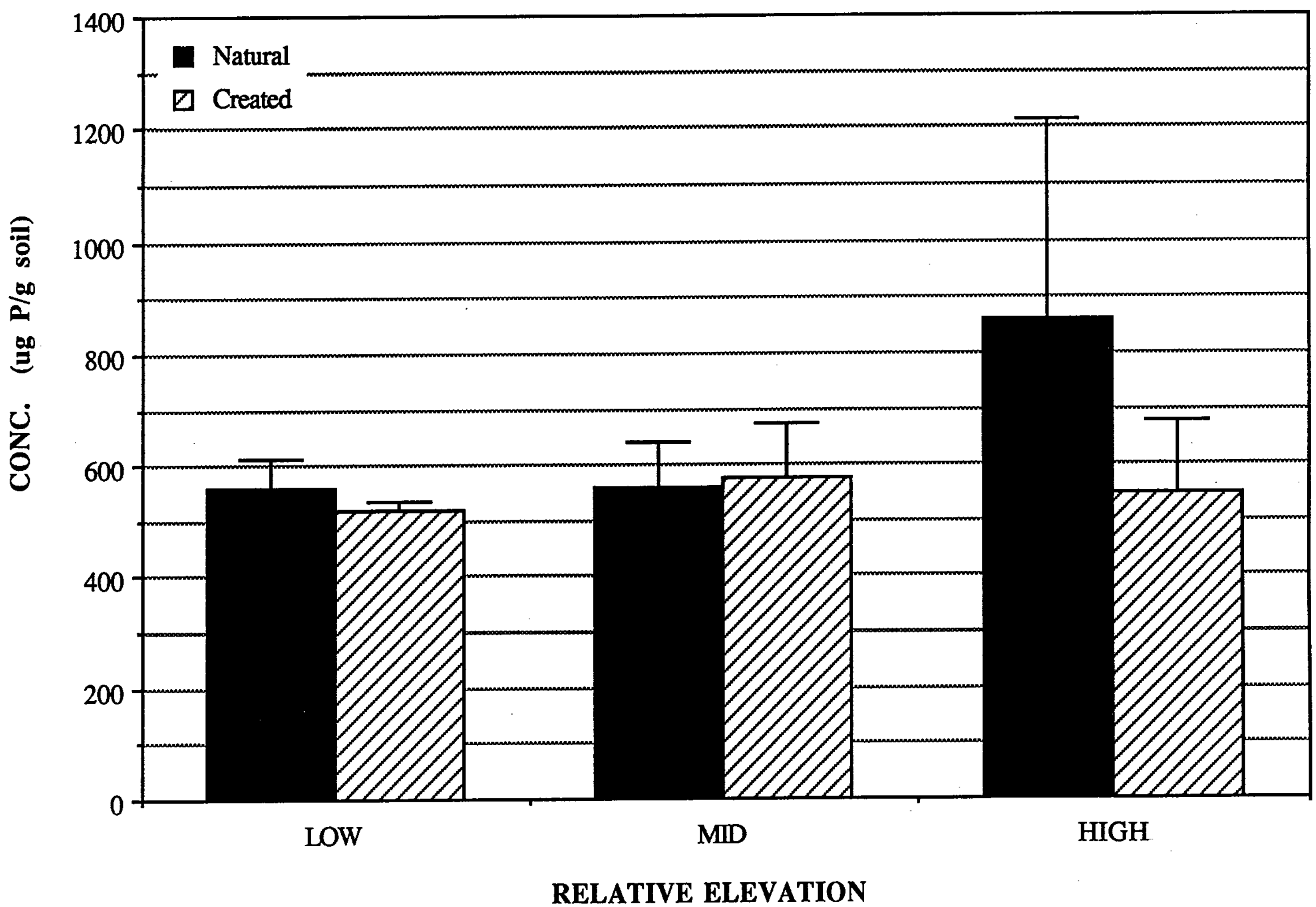

Figure A50. Comparison by elevation of mean (1 std. dev.) total soil phosphorus concentrations in old natural and created wetland soils (July 1994)

Appendix B Vegetation Found in the Atchafalaya Delta Wetlands

Aeschynomene indica

Althernanthera philoxeroides

Ammania coccinea

Andropogon virginicus

Apios americana

Baccharis halimifolia

Bidens laevis

Cacopa monnierri

Ceratophyllum demersum

Colocasia antigorum

Crinum americanum

Cyperus spp.

Cyperus cuspidatus

Cyperus difformis

Cyperus oderatus

Cyperus retrorsus

Dichromena colorata

Echinochloa crusgalli

Echinochloa walteri

Eichhornia crassipes

Eleocharis spp.

Eleocharis parvula

Eleocharis rostalata

Galium tinctorium

Hydrocotyle spp.

Ipomea sagittata

Iris virginica

Justicia ovata

Leersia oryzoides

Ludwigia leptocarpa

Lythrum lineare

Panicum virgatum

Paspalum spp.

Phyla nodiflora

Pluchea camphorata

Polygonum punctatum

Pontederia cordata

Potamogeton spp.

Sagittaria lancifolia

Sagittaria latifolia

Sagittaria platyphylla

Salix nigra

Scirpus americanus

Scutellaria lateriflora

Sesbania drummondii

Solidago spp.

Sphenoclea zeylandica

Spilanthes spp.

Sporobolus virginicus

Tradescantia fluminensis

Typha domingensis

Vigna luteola

Zizania milliaceae

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13. ABSTRACT *(Maximum 200 words)*

Functional assessment of created wetlands in comparison with natural wetlands of the same ages was undertaken in the Atchafalaya Basin, Louisiana. Overall objectives were to characterize the structural components (soils and vegetation) of created and natural wetlands of similar age classes, compare and contrast selected wetland functions, and quantify any structural and functional changes that may occur as a function of time.

The Atchafalaya Basin was selected for this study because it is one of the few locations in the United States with newly forming natural wetlands and a number of created/restored wetlands available for comparison. Aerial photography, satellite imagery, and Corps records were used to select one natural and one created wetland for each of three age classes: young (1 to 3 years), intermediate (5 to 10 years), and old (15 to 20 years). An additional natural "old" wetland was added to assure a valid comparison.

Soils were evaluated for bulk density, pH, moisture content, particle size, phosphorus content, and nitrogen (N-mineralization, total N, carbon, nitrous oxide, and denitrification enzyme activity) content. No seasonal differences for the three age classes were found in the N, P, pH, particle size, and moisture content samples; however, a trend of increasing soil N with increasing elevation was noted for the older marshes. Bulk density was highest in the young age class and lowest in the old age class. Phosphorus concentrations were similar in both created and natural marshes at lower elevations, but were higher at higher elevations.

(Continued)

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A total of 53 plant species were found in all wetlands studied, with a clear separation by elevation. The lowest level was unvegetated mud flats, followed by distinct zonations. Old wetlands were different from new wetlands in dominant species, and created wetlands of all ages had a higher diversity of species. Total aboveground biomass was lower on created wetlands, but may have been due to nutria herbivory. Presence of woody vegetation that could not be destructively sampled complicated vegetation biomass data comparisons.

New created marshes had obvious differences attributable to the dredging process necessary to create the wetland. These initial differences were overcome through time with deposition of fine-textured, nutrient-rich suspended sediments on the soil surface during flooding events. A similar convergency of vegetation characteristics took place during this same interval. Results indicated that it takes from 5 to 10 years for a created wetland in the Atchafalaya Delta to develop similar soil and vegetation characteristics to a natural reference wetland of the same age.

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